JPL D-39032

Moon Mineralogy Mapper

DATA PRODUCT
SOFTWARE INTERFACE SPECIFICATION

Version 9.3

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DOCUMENT CHANGE LOG

Change	Date	Affected Portions
Swap items 6 and 7	7/30/07	Secton 2.4.3.3
Add data quality	7/31/07	Section 2.4.3.5
Change Level 1A to Level 1B	8/02/07	All
Change non-resampled to resampled	8/02/07	All
Change data quality image extension from rdnq* to dq*	8/16/07	Pages 5, 12, 28
Added line item to TBD Items	1/25/08	TBD Items table
Switch position of latitude and longitude	2/12/08	Pages 24, 25
Removed data quality images	3/19/08	
Changed *_rdn.lbl to *_l1b.lbl	5/21/08	Pages 5
Added Decimal Day of Year	5/21/08	Page 12
Added DDOY to UTC Timing section	5/21/08	Page 28
Accepted all tracked changes	6/24/08	
Changed *TIM.TXT to *TIM.TAB and revised UTC timing file description	8/26/08	Page 5, 13, 27
Added Level 2 data products; Added J.Sunshine as a signatory (S. McLaughlin)	8/28/08	Most sections
Update L0 Image Frame Header details	9/9/08	Section 3
Added “incidence angle” and “emission angle” to help clarify to-sun and to-sensor zenith angles, respectively; Provided the baseline equation and inputs for converting from L1B radiance to reflectance	9/23/08	TDB Items, Sections 2.4.3.3 and 2.4.4
Added description of image time frame discrepancies between L0 and L1B data products.	9/25/08	Sections 3.1.1.2 and 3.1.2.9
Changed data storage type for L2 from 32-bit reals to 16-bit signed integers where 30000 represents 100% reflectance; Adding SCALING_FACTOR to the L2 PDS label example and L2 ENVI header; Changed the PDS dictionary namespace from M3: to CH1: in the L2 PDS labels.	11/20/08	TDB Items; Sections 2.4.4, 2.4.4.1, 3.3.1.2.1, 3.3.1.2.2, 3.3.1.3.1, 3.3.1.3.2; Figure 3-5; Appendix C
Updated L0, L1B, and L2 PDS label examples	01/07/09	Appendices A, B, C
Updated 16-bit to 32-bit for L1B radiance products and L2 reflectance products	01/26/09	Sections 3.2.1
Updated number of bands from 86 to 85 for L1B Global Mode data	07/07/09	Sections 3.2.1
Changed “Figure 2-2” to “Figure 3-1” and “Figure 2-3” to “Figure3-2” Converted *_obs.img to uppercase Changed last sentence from “Example Level 1B…” to “An Example Level 1B…”	11/04/09	Sections 3.1.1.2, 3.2.1.4

TBD ITEMS

Section	Description
2.6	Data validation key steps.
3.3 M^3 Level 2 Data Products	a) Data lost due to dropped packets or decompression are flagged with values of -2 or -3 in Level 1B. Will these values be carried to Level 2 or should other values be used?
2.4.3.1	Add specific radiometric calilbration steps. Make sure to include the names of files to be included in EXTRAS (image-based flat field files, bad detector element map)

ACRONYMS

ACT	Applied Coherent Technology Corporation
ASCII	American Standard Code for Information Interchange
AU	Astronomical Unit
BDE	Bad Detector Element Image
BIL	Band Interleaved By Line Format
BIP	Band Interleaved By Pixel Format
BSQ	Band Sequential Format
CCSDS	Consultative Committee on Space Data Systems
CK	SPICE Camera-matrix Kernel
CODMAC	Committee on Data Management, Archiving, and Computing
DDOY	Decimal Day of Year
DEM	Digital Elevation Model
DN	Digital Numbers
DSS	Dark Signal Subtracted Image
ECR	Engineering Change Request
EDR	Experiment Data Record
ENVI	Environment for Visualizing Images
EXT	File Name Extension
FF	Flat Field Image
FK	SPICE Frame Definition Kernel
FWHM	Full-width-at-half-maximum
FOV	Field-of-view
HDR	Detached Header File
ICD	Interface Control Document
IDL	Interactive Data Language
IFOV	Instantaneous Field-of-View
IGDS	Instrument Ground Data System (JPL)
IMG	Image
ISO	International Standards Organization

ISRO	Indian Space Research Organization
ISSDC	Indian Space Science Data Center (ISRO)
ITT	International Telephone & Telegraph
JPL	Jet Propulsion Laboratory
L0	Level 0 Data Product
L1B	Level 1B Data Product
L2	Level 2 Data Product
LBL	Detached Label File
LOC	Pixel-Located Data
LOLA	Lunar Orbiter Laser Altimeter (NASA)
LGCWG	Lunar Geodesy and Cartography Working Group
LRO	Lunar Reconnaissance Orbiter (NASA)
MCT	Mercury-Cadmium-Telluride
ME	Mean Earth
MMM/M3	Moon Mineralogy Mapper (JPL/NASA)
NASA	National Aeronautics and Space Administration
OBS	Observation Geometry Data
NIST	National Institute of Standards and Technology
NM	Nanometer
OBT	On-board Timer
PCU	Power Conditioning Unit
PDS	Planetary Data System
RCC	Radiometric Calibration Coefficient
RDN	Spectral Radiance Data
RFL	Spectral Reflectance Data
ROLO	Robotic Lunar Observatory
SCIF	Spacecraft Interface
SCLK	SPICE Spacecraft Clock Coefficients Kernel
SDP	Science Data Processor
SIS	Software Interface Specification
SPK	SPICE Space Vehicle/Target Body Trajectory (Ephemeris)

	Kernel
TAB	ASCII Data Table
TBD	To Be Determined
TIM	Observation Timing Data
ULCN	Unified Lunar Control Network
UMD	University of Maryland
UTC	Coordinated Universal Time
VIS	Visual Information Solutions

1. Introduction

1.1. Purpose and Scope

The purpose of this Data Product Software Interface Specification (SIS) is to provide users of the data products from the Moon Mineralogy Mapper (M^3) with a detailed description of the products and how each was generated, including data sources and destinations.

There are three M^3 data products defined in this SIS document. These include:

1) NASA Level 0 consisting of raw, science data in units of DN.
2) NASA Level 1B consisting of resampled calibrated data in units of spectral radiance, pixel center location data, observational geometry and illumination parameters, and UTC timing information for each image frame.
3) NASA Level 2 consisting of photometrically calibrated reflectance data (unitless).

Files used to reduce or calibrate the Level 1B and 2 data products are also described:

1) Spatial, spectral, and radiometric files used to generate radiance values in a Level 1B product from a Level 0 product.
2) File of photometric correction factors used to generate reflectance values in a Level 2 product from a Level 1B product.

This SIS is intended to provide enough information to enable users to read and understand the data product. The users for whom this document is intended are the scientists who will analyze the data, including those associated with the project and those in the general planetary science community.

1.2. Contents

This Data Product SIS describes how data products generated by M^3 are processed, formatted, labeled, and uniquely identified. The document details standards used in generating the products and software that may be used to access the product. Data product structure and organization is described in sufficient detail to enable a user to read the product. Finally, an example of each product label is provided.

1.3. Applicable Documents and Constraints

This Data Product SIS is responsive to the following Moon Mineralogy Mapper documents:

1. M^3 Project Data Management and Archive Plan, S. R. Lundeen and J. M. Diehl, Ver 2.6, March 24, 2010.
2. M^3 Instrument Electronic Assembly Internal ICD for Space Craft Interface Assembly, Science Data Processor (SDP), and Power Conditioning Unit (PCU), Brass Board & Flight Model (as altered by ECRs), August 2006.

3. M^3 Archive Volume Software Interface Specification, S. R. Lundeen, R. Alanis, and S. McLaughlin, Version 3.2, April 12, 2010, JPL D-38529.
4. M^3 Instrument Ground Data System, UMD/ACT, and PDS Imaging Node Interface Control Document, Version 4.2, January 25, 2008, JPL D-37304.

This SIS is also consistent with the following Planetary Data System documents:

5. Planetary Data System Archive Preparation Guide, June 4, 2008, Version 1.3, JPL D-31224.
6. Planetary Data System Standards Reference, February 27, 2009, Version 3.8. JPL D-7669.
7. Planetary Science Data Dictionary Document, Rev. E, August 28, 2002.

The reader is referred to the following documents for additional information (documents 9 and 10 are included in EXTRAS):

8. The Unified Lunar Control Network 2005, 2006, Archinal et al., 2006, Version 1.0, http://pubs.usgs.gov/of/2006/1367
9. A Standardized Lunar Coordinate System for the Lunar Reconnaissance Orbiter and Lunar Datasets, LRO Project and LGCWG White Paper, Version 5, October 1, 2008, http://lunar.gsfc.nasa.gov/library/LunCoordWhitePaper-10-08.pdf
10. Lunar Constants and Models Document, September 23, 3005, JPL D-32296, http://ssd.jpl.nasa.gov/dat/lunar_cmd_2005_jpl_d32296.pdf

1.4. Relationships with Other Interfaces

Level 0 and 1B data products described in this SIS are produced by the M^3 Instrument Ground Data System (IGDS) located at NASA's Jet Propulsion Laboratory (JPL). Level 2 data products are produced by the University of Maryland (UMD) in partnership with Applied Coherent Technology Corporation (ACT). Changes to the IGDS processing algorithms may cause changes to the data products and thus, this SIS. The Level 1B products are dependent on the M^3 Level 0 products, and Level 2 products are dependent of Level 1B. As such, changes to the Level 0 product may affect the Level 1B and Level 2 products. Changes to the Level 1B product may affect Level 2.

Changes in M^3 data products or this SIS may affect the design of the M3 archive volumes.

1.5. Image Display and Analysis Software – ENVI/IDL

The commercial software packages ENVI and IDL can be used to display and analyze Level 0, Level 1B and Level 2 data products (suffix *.IMG). ENVI and IDL are distributed by ITT Visual Information Solutions (http://www.ittvis.com/). M^3 data products are in no way in any proprietary format. Instead they are arranged as simply and as openly as possible.

ENVI uses a general raster data format consisting of a simple flat binary file and a small associated ASCII (text) header file (suffix *.HDR). This enables ENVI's flexible use of nearly any image format, including those with embedded header information.

See Appendix D for basic M^3 .IMG display instructions.

M^3 data can also be displayed with PDS's NASAView software package. For more information, see Section 4.1.

2. DATA PRODUCT CHARACTERISTICS AND ENVIRONMENT

2.1. Instrument Overview

The Moon Mineralogy Mapper (M^3) was selected as a NASA Discovery Mission of Opportunity in February 2005. The M^3 instrument was launched on October 22, 2008 at 00:52:02 UTC from Shriharikota in India on board the Indian Space Research Organization (ISRO) Chandrayaan-1 spacecraft for a nominal two-year mission in a 100 km polar orbit. The M^3 instrument is a high uniformity and high signal-to-noise ratio imaging spectrometer that operates in the solar dominated portion of the electromagnetic spectrum with wavelengths from 430 nm to 3000 nm (0.43 to 3.0 microns) in a high-resolution Target Mode and in a reduced-resolution Global Mode. Target Mode pixel sizes are nominally 70 meters and Global pixels (binned 2 by 2) are 140 meters, from the planned 100 km orbit.

The basis for the use of imaging spectroscopy for mapping the mineralogy of the Moon is shown in the diversity of lunar mineral spectral signatures illustrated in Figure 2-1.

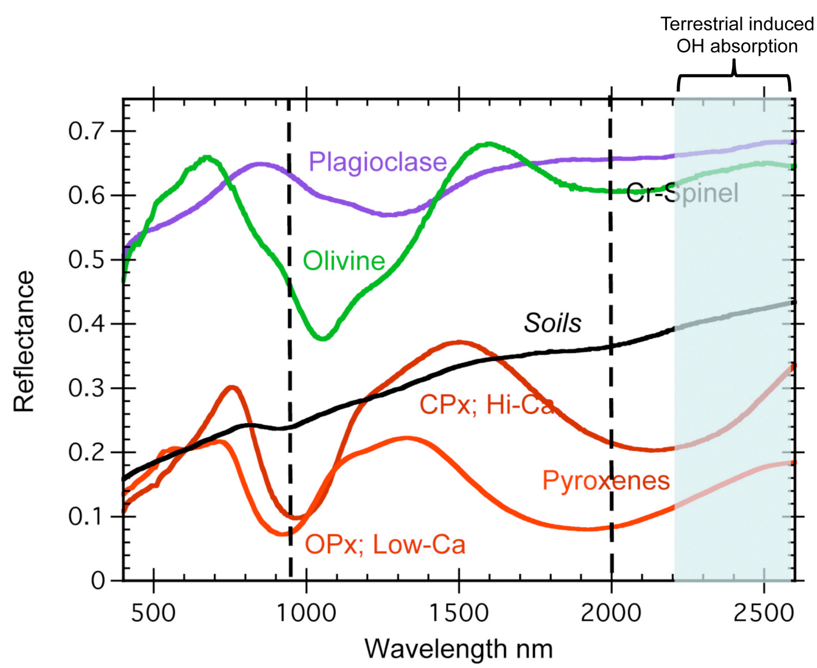


Figure 2-1. Selected reflectance spectra of lunar minerals.

For the M^3 Mission, a high throughput and uniformity optimized Offner imaging spectrometer design[1] was selected and is shown in Figure 2-2. This design uses a compact three-mirror telescope that feeds light through a uniform slit to spectrometer with one spherical mirror and a custom convex grating. The dispersed light from the spectrometer then passes through an order-sorting filter to the detector array that is sensitive from 430 to 3000 nm. This design is enabled by the structured blaze convex grating in the core of the uniform full-range spectrometer. The mass and power of the M^3 instrument are ~8 kilograms and ~15 Watts average. The volume of the optical and detector assembly is 25 X 18 X 12 centimeters.

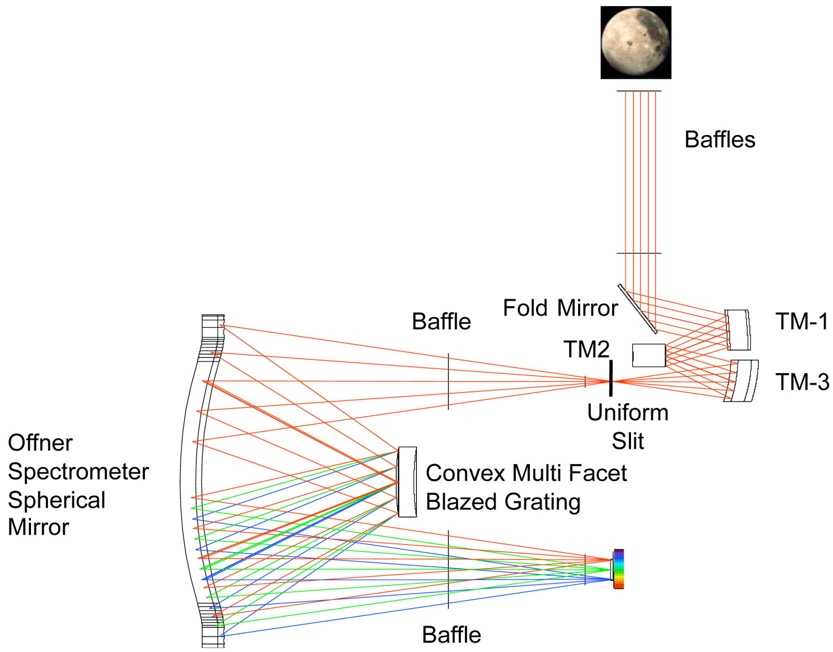


Figure 2-2. Optical layout of the M^3 imaging spectrometer instrument.

A summary of the spectral, radiometric, spatial and uniformity characteristics of the M^3 instrument are given in Table 2-1.

Table 2-1. Key M^3 Measurement Characteristics

Spectral	
Range	430 to 3000 nm
Sampling	10 nm constant
Response	FWHM <15 nm
Radiometric	
Range	0 to specified saturation

Sampling	12 bits measured,
Response	Linear to 1%
Accuracy	Within 10% absolute
Precision (SNR)	>400 @equatorial reference
	>100 @polar reference
Spatial	
Range	24 degree field-of-view
Sampling	0.7 milliradian
Response	FWHM < 1.0 milliradian
Uniformity	
Spectral-cross-track	< 10% variation of spectral position across the field-of-view
Spectral-IFOV	< 10% IFOV variation over the spectral range

The M^3 instrument was completed in April of 2007. A picture of the completed instrument optical assembly and passive radiator is shown in Figure 2-3.

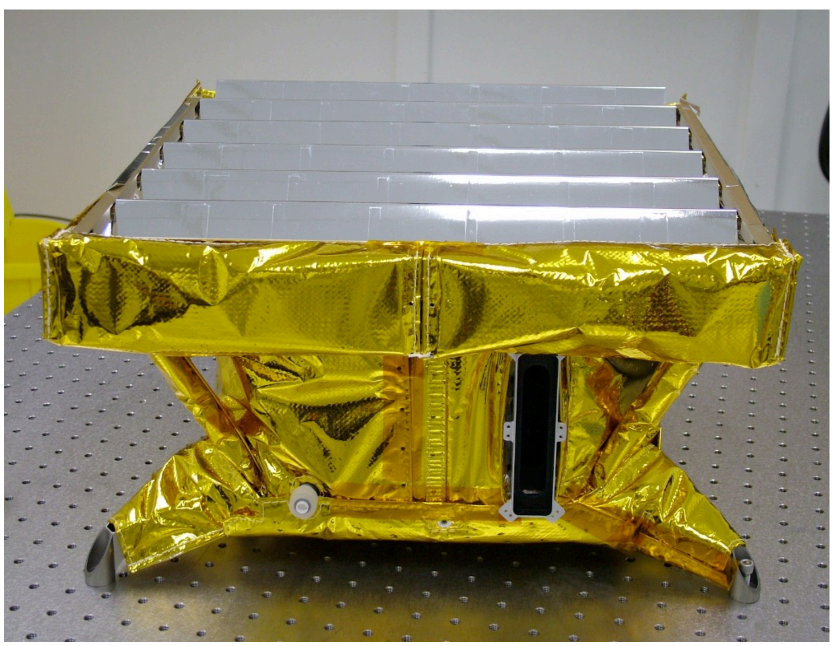


Figure 2-3. Completed M^3 instrument optical assembly and passive radiator (the entrance to the telescope is shown with the cross-track swath in a vertical orientation).

2.2. Instrument Operations Overview

The M^3 image acquisition time will be divided into peak periods or Optical Periods (OP) when lighting is optimal for observation. The Optical Periods occur twice a year and are understood to have two central months of optimal illumination (solar beta angles -30° to +30°) with two optional two-week wing periods (solar beta angles ±30° to ±45°) on either side of the optimal 2 months (thus, one Optical Period equals 13 weeks). Each 13 week optical period is followed by a 13-week hiatus. The original instrument operations plan included the acquisition of the entire surface of the Moon in low-resolution Global Mode during the first Optical Period (OP1) while OP2, OP3, OP4 were reserved for high resolution Target Mode data acquisition.

However, the mission was cut short, just before the halfway point, in August, 2009 when the spacecraft ceased operations. Despite the abbreviated mission and numerous technical and scientific challenges during the flight, M^3 was able to cover more than 95% of the Moon in Global Mode. Only minimal high-resolution Target Mode images were acquired, as these were to be the focus of the second half of the mission. The technical challenges encountered during the mission have complicated the data processing and calibration. These challenges include thermal issues, loss of the spacecraft star trackers and a raising of the orbit from 100 km to 200 km on May 19, 2009. Details of these challenges are currently being documented and will be referenced and/or included in the delivery of the M^3 PDS Archive Volume. Nonetheless, the data products released in the M^3 PDS Archive Volume will contain optimal calibration and characterization.

M^3 operations were sustained for two Optical Periods. (For more detailed information regarding the spacecraft operation schedule, please see the MISSION.CAT.) Each Optical Period can be broken into sub-Ops based on instrument or spacecraft events and status. Table 2-2 provides an overview and description of each sub-OP. Figure 2-4 shows the M^3 coverage during both Optical Periods along with a cumulative coverage index of the gaps, the nearly full Global coverage and the limited Target images.

Table 2-2. Overview of M^3 Operations by Optical Period

Sub-OP Name	Description	Time Period
OP1A	Commissioning phase through “warm” data	2008 Nov 18 to 2009 Jan 24
OP1B	Start of “cold” data through end of OP1	2009 Jan 09 to 2009 Feb 14
OP2A	100 km orbit with star trackers	2009 Apr 15 to 2009 Apr 27
OP2B	100 km orbit, no star trackers	2009 May 13 to 2009 May 16
OP2C	200 km orbit, no star trackers	2009 May 20 to 2009 Aug 16

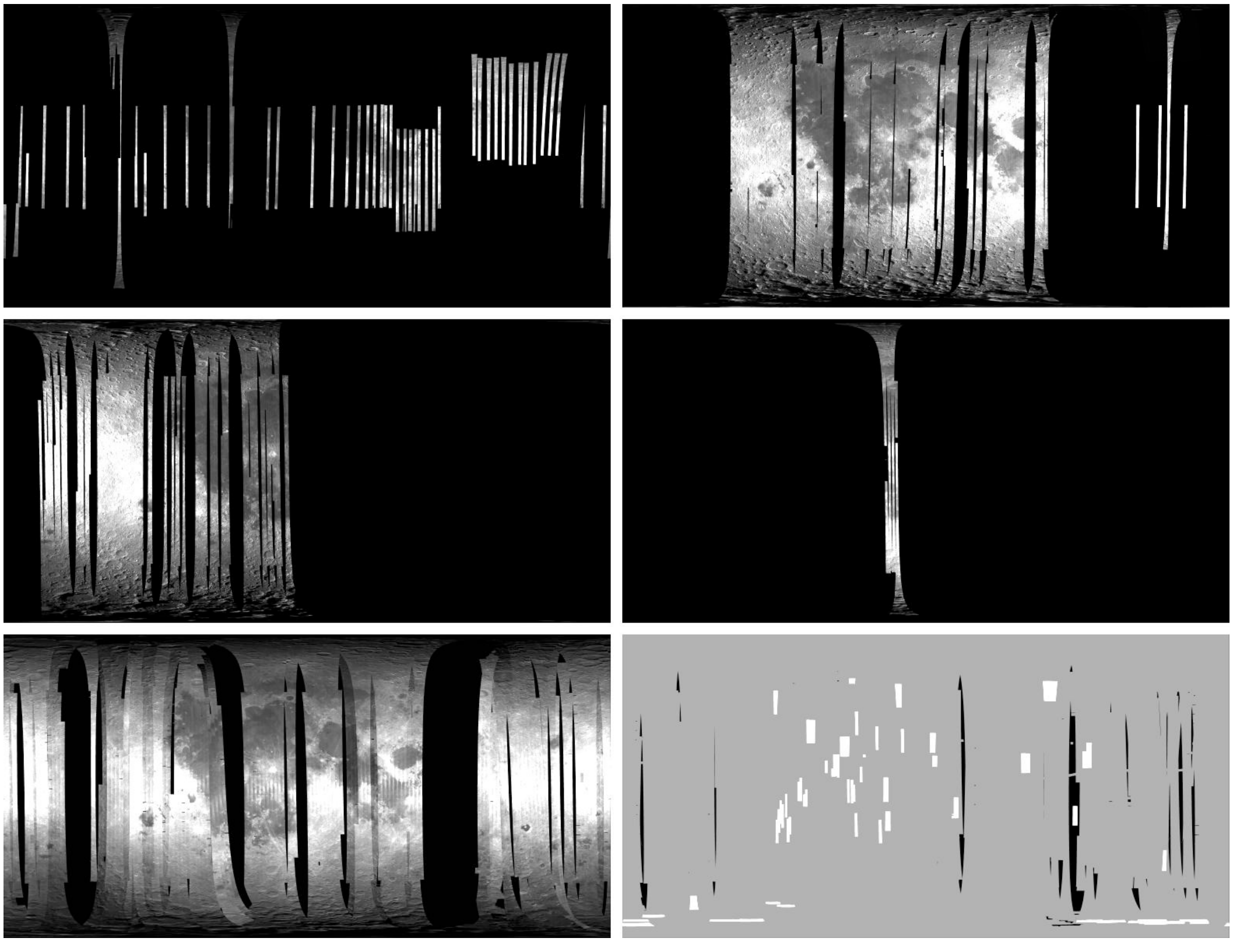


Figure 2-4. M^3 coverages by five sub-Optical Periods (from left to right, OP1A, OP1B, OP2A, OP2B, OP2C) and a cumulative coverage index (black/gray/white = gaps/global/target).

2.3. Data Product Overview

The two M^3 standard data products referred to collectively as M^3 Level 0 and M^3 Level 1B data products include raw images and radiometrically-calibrated, pixel-located spectral images acquired in either global or target mode. Table 2-4 provides details of the M^3 operating modes. The third M^3 standard data product referred to as M^3 Level 2 includes photometrically calibrated, pixel-located reflectance spectral images. All images are stored in binary format with a detached ASCII PDS label and a detached ASCII ENVI-compatible header file.

All M^3 data products are stored in Band-Interleaved-By-Line (BIL) image file format. BIL format stores the first line of the first band, followed by the first line of the second band, followed by the first line of the third band, interleaved up to the number of bands. Subsequent lines for each band are interleaved in similar fashion. This format provides a compromise in performance between spatial and spectral processing

A M^3 Level 0 data product consists of raw, science data in units of DN that make up one observation tagged by a unique file name. The data in one Level 0 Product represent a consistent instrument configuration (frame rate, pixel binning). A Level 0 Data Product is comprised of a single multiple-band image (suffix *_L0.IMG) stored in one file, plus a detached PDS label (ASCII; suffix *_L0.LBL).and a detached header file (ASCII; suffix *_L0.HDR).

A M^3 Level 1B Data Product consists of pixel-located, resampled, calibrated data in units of spectral radiance that make up one observation tagged by a unique file name. The data in one Level 1B Product represent a consistent instrument configuration (frame rate, pixel binning). There is a single multiple-band image (BIN; suffix *_RDN.IMG) stored in one file with a detached PDS label (ASCII; suffix *_L1B.LBL), and a detached header file (ASCII; suffix *_RDN.HDR), plus several files containing data related to pixel-located (BIN; suffix *_LOC.IMG), observation geometry (BIN; suffix *_OBS.IMG), and UTC timing for each image line (ASCII; suffix *_TIM.TAB).

A M^3 Level 2 Data Product consists of pixel-located, resampled, photometrically calibrated, reflectance data (unitless) that make up one observation tagged by a unique file name, and there is one Level 2 data product for each Level 1B radiance image. Therefore the data in one Level 2 Product represent a consistent instrument configuration (frame rate, pixel binning). There is a single multiple-band image (BIN; suffix *_RFL.IMG) stored in one file with a detached PDS label (ASCII; suffix *_L2.LBL), and a detached header file (ASCII; suffix *_RFL.HDR).

2.4. Data Processing

2.4.1. Data Processing Level

This SIS uses the NASA data level numbering system to describe the processing level of M^3 data products. Table 2-3 shows the description of the Committee On Data Management And Computation (CODMAC) data processing levels and the correlation with the NASA processing levels. All M^3 data products comply with NASA processing levels standards. The CODMAC system is mentioned here because it is the standard used by the PDS.

Table 2-3. Processing Levels for Science Data Sets

NASA Level	Description	CODMAC Level	Description
		1-Raw Data	Telemetry data with data embedded.
0	Instrument science packets (e.g., raw voltages, counts) at full resolution, time ordered, with duplicates and transmission errors removed. Corresponds to Space Science Board's Committee on Data Management and Computation (CODMAC) Edited Data (see National Academy press, 1986).	2-Edited Data	Corrected for telemetry errors and split or decommutated into a data set for a given instrument. Sometimes called Experimental Data Record. Data are also tagged with time and location of acquisition. Corresponds to NASA Level 0 data.
1A	Level 0 data which have been located in space and may have been transformed (e.g. calibrated, rearranged) in a reversible manner and packaged with needed ancillary and auxiliary data (e.g., radiances with the calibration equations applied). Corresponds to CODMAC Calibrated Data.	3-Calibrated Data	Edited data that are still in units produced by instrument, but that have been corrected so that values are expressed in or are proportional to some physical unit such as radiance. No resampling, so edited data can be reconstructed. NASA Level 1A.
1B	Irreversibly transformed (e.g., resampled, remapped, calibrated) values of the instrument measurements (e.g., radiances, magnetic field strength). Corresponds to CODMAC Resampled Data.	4-Resampled Data	Data that have been resampled in the ti me or space domains in such a way that the original edited data cannot be reconstructed. Could be calibrated in addition to being resampled. NASA Level IB.
1C	Level 1A or 1B data, which have been resampled and mapped onto, uniform space-time grids. The data are calibrated (i.e., radiometrically corrected) and may have additional corrections applied (e.g., terrain correction). Corresponds to CODMAC Derived Data.	5-Derived Data	Derived results, as maps, reports, graphics, etc. NASA Levels 2 through 5.
2	Geophysical parameters, generally derived from Level 1 data, and located in space and time commensurate with instrument location, pointing, and sampling. Corresponds to CODMAC Derived Data.	5-Derived Data	Derived results, as maps, reports, graphics, etc. NASA Levels 2 through 5.
3	Geophysical parameters mapped onto uniform space-time grids. Corresponds to CODMAC Derived Data.	5-Derived Data	Derived results, as maps, reports, graphics, etc. NASA Levels 2 through 5.
		6-Ancillary Data	Nonscience data needed to generate calibrated or resampled data sets. Consists of instrument gains, offsets, pointing information for scan platforms, etc.
		7-Correlative Data	Other science data needed to interpret space-based data sets. May include groundbased data observations such as soil type or ocean buoy measurements of wind drift.
		8-User Description	Description of why the data were required, any peculiarities associated with the data sets, and enough documentation to allow secondary user to extract information from the data.
		N	Not Applicable

Table 2-4. Description of M3 Operating Modes

M^3 Mode	Description	Data Product	Num of Channels	Num of Samples	Data Product Format
Target	Target Mode produces the maximum spectral resolution science data.	Level 0	260	640	16-bit Integer
		Level 1B	255	610	32-bit Floating Point
		Level 2	255	610	32-bit Floating Point
Global	Global Mode reduces spectral resolution by 3 times. • 4 block of 2x and 4x summing • 44 lines of summed by 4x and 42 lines of summed by 2x The spatial data is summed in a 2 by 2 format.	Level 0	86	320	16-bit Integer
		Level 1B	85	304	32-bit Floating Point
		Level 2	85	304	32-bit Floating Point

2.5. Data Product Generation

2.5.1. Overview

Level 0 and Level 1B standard products are generated in the M^3 Instrument Ground Data System (IGDS) at JPL. Level 2 standard products for delivery to the PDS is managed by the University of Maryland (UMD) in partnership with Applied Coherent Technology Corporation (ACT). Each Level 0 and Level 1B, and Level 2 data file contains data acquired while the spacecraft is on the illuminated side of a single orbit.

2.5.2. Level 0 Data Processing

The data received on the ground are in the form of compressed, 8-bit “digital numbers” (DN). Level 0 processing involves identification of the raw science telemetry packets, processing secondary header time stamps, decompressing the data into 16-bit, signed integers and reassembling the packets into time-sequenced image cubes for further data processing. Packet check sum errors, out of sequence packets, compression errors, and missing packet errors are flagged in the Level 0 Product.

2.5.3. Level 1B Data Processing

Level 1B data is irreversibly transformed; Level 1B processing involves the following operations:

- converts the decompressed, uncalibrated image cube data into resampled, scaled, calibrated spectral radiance image cubes
- calculates the lunar surface location of all pixel centers
- calculates the observation geometry and illumination on a pixel-by-pixel basis
- calculates the UTC time for the middle of the integration period for each frame of the image data

2.5.3.1. Spectral Radiance Calibration

The calibration of M^3 took place during the month of April 2007. A complete set of spectral, radiometric, spatial and uniformity calibration measurements were acquired. Figure 2-5 shows an M^3 image of a laser-illuminated integrating sphere with wavelengths of 532, 1064, 2065 nm across the field-of-view (FOV). The calibrated spectral range is from 403.9 to 2982.8 nm. Spectral sampling was measured as 9.995 nm (constant through the entire band). A scanning monochromator was used to establish the spectral response functions over the entire spectral range. Figure 2-6 shows a set of M^3 measured spectral response functions in the range from 2000 to 2200 nm.

Figure 2-5. M^3 FOV measurement of three laser lines for determination of spectral range and sampling (600 cross-track samples by 260 spectral channels).

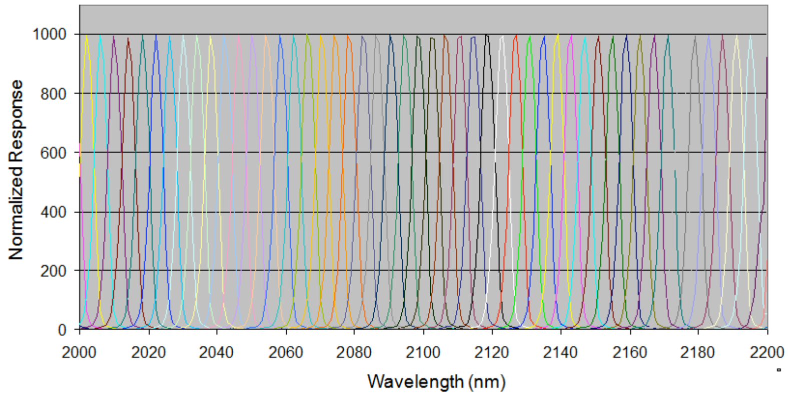


Figure 2-6. M^3 spectral response function subset from 2000 to 2200 nm.

Radiometric calibration was traced to a National Institute of Standards and Technology (NIST) irradiance lamp and a reflectance panel standard. Figure 2-7 shows an M^3 calibrated measurement of the radiometric calibration source. With radiometric calibration and instrument noise measurement, the signal-to-noise ratio of M^3 was calculated for the polar and equatorial reference radiances and is shown in Figure 2-8.

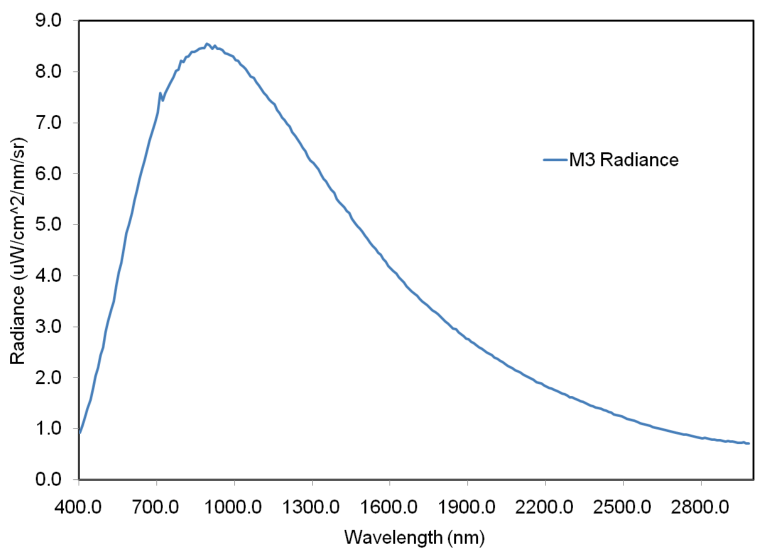


Figure 2-7. Radiometrically calibrated M^3 measurements from laboratory radiance standard.

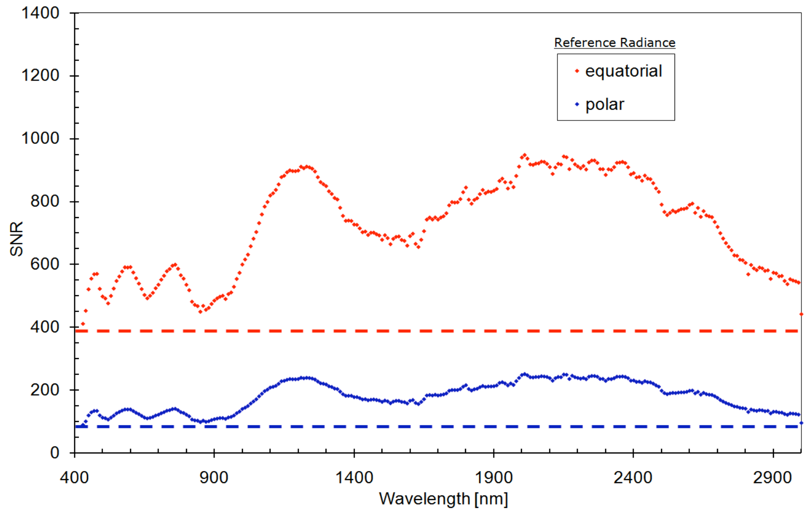


Figure 2-8. M^3 calculated signal-to-noise ratio based on laboratory measured instrument throughput and noise and signal from Apollo 16 soil at 0 and 80 degrees zenith.

The spatial field-of-view (FOV), sampling, and response function were measured as well. The image FOV of M^3 is 24 degrees with a cross-track sampling of 0.7 milliradians. The full-width-at-half-maximum (FWHM) for the spatial response function was measured as ~1 milliradian.

The imaging spectrometer uniformity of M^3 was specified at > 90% for both the spectral cross-track uniformity and spectral-IFOV (instantaneous field-of-view) uniformity. Figure 2-9 shows the spectral cross-track uniformity measured from a Neodymium spectral target. Figure 2-10 shows the spectral-instantaneous-FOV uniformity measured from a cross-track scanning white-light slit through a collimator.

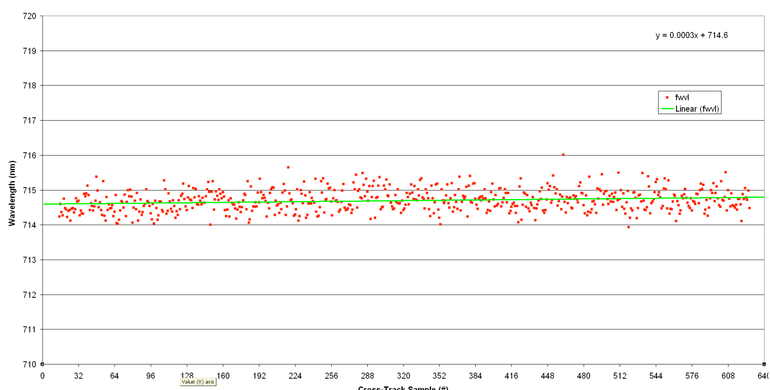


Figure 2-9. M^3 spectral cross-track uniformity. There is less than 0.5 nm cross-track spectral variation with respect to 10 nm spectral sampling.

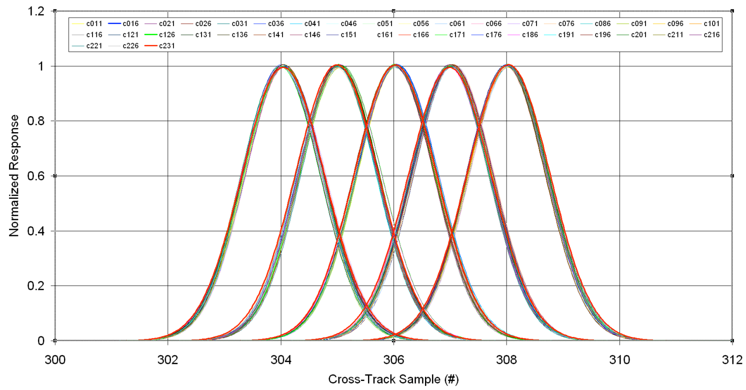


Figure 2-10. Derived M^3 spectral-IFOV uniformity over the spectral range. The blue spatial response curve is from the visible and the red in from 2800 nm.

Based upon these laboratory measurements as well as on-orbit assessment of the measured lunar data a series of calibration processing steps are applied to convert the report Digitized Number (DN) to units of spectral radiance. A description of these calibration processing steps is given below. An article titled "The NASA Moon Mineralogy Mapper (M^3) Imaging Spectrometer for Lunar Science: Instrument Description, Calibration, and On-orbit Performance," is in preparation and will provide further description of the calibration processing algorithms and sequence for M3.

Dark signal subtraction: For nominally acquired M^3 data sets a dark signal data set is acquired on the unilluminated side of the Moon prior to acquisition of the illuminated data set. This dark signal data set is averaged for all lines to generate a dark signal average with one value for each spatial and spectral sample. For Target mode data this is an array of 640 by 260 real dark signal values. For Global mode data this is an array of 320 by 86 real dark signal values. The dark signal subtracted (DSS) image is generated by subtracting the dark signal average values from the corresponding illuminated signal M^3 image. In cases where a dark signal image was not specifically acquired with an illuminated image, the nearest dark signal image is used.

Bad detector element correction: M^3 uses 166400 detector elements of the 6604a mercury-cadmium-telluride (MCT) detector array. A number of these detector elements exhibit non standard behavior ranging from non-responsive high and low to excessively noisy. These non standard detector elements are referred to as bad detector elements (BDEs). The number of BDEs varies somewhat with time and is also a function of the temperature of the detector array. For each illuminated M^3 image the number and location of BDEs is determined by calculating the mean and standard deviation of the signal in the corresponding dark signal image. Detector elements that are non-responsive or excessively noisy are flagged in a BDE image (640 spatial by 260 spectral for Target Mode and 320 spatial by 86 spectral for Global Mode). The identified bad detector elements are replaced in the DSS image using simple linear interpolation in the spectral direction.

Detector array tap interpolation: The 6604a detector array is read out in four zones that are tied to columns 1, 161, 321, and 481 in the cross-track, 640 dimension. In the M^3 signal chain electronics these columns are severely impacted by the readout and the values are replaced with simple linear interpolation using the samples on each side of the impacted column. For target mode these interpolated columns are 161, 321 and 481. For Global mode data these interpolated columns are 81, 161, and 241.

Filter seam interpolation: The order sorting filter directly in front of the detector array has seams between the filter zones that impact the quality of the data recorded. To suppress the impact from the filter seams the detectors below the seams are replaced with simple linear interpolations in the spectral direction. The spectral channels that are replaced for Target Mode are 41, 42 and 116. Channels 13 and 50 are replace in Global Mode data.

Electronic panel ghost correction: As the M^3 6604a detector array signal chain is readout through the four outputs a small electronic ghost is generated. For example, if a bright signal is present at cross-track sample 50, as small negative signal will be imparted in the other three detector zones at sample 50+160, 50+320 and 50+480. This has been assessed based on laboratory and on-orbit measurements as a 0.0048 signal fraction effect. A simple fractional correction processing step is applied to the DSS image to suppress this electronic panel ghost artifact.

Dark pedestal shift correction: Another characteristic of the M^3 6604a signal chain is expressed as a small drop in the dark signal level when the array is illuminated. This effect is captured by a set of dark masked detector array elements in cross-track columns 1-8 and 637-640. With these dark masked detector elements a function has been developed to estimate the dark pedestal shift based upon the signal in the illuminated portion of the array. This correction is applied to the image on a line by line based to compensate for the dark pedestal shift in the DSS image.

Scattered light correction: Late during laboratory characterization/calibration, anomalous scattered light was identified dominantly impacting the short wavelength portion of the spectrum. M^3 was designed with columns of detector elements that are nominally vignetted by the spectrometer slit. Signal arriving at these detectors provides an estimate of the scattered light. These vignetted column detector elements correspond to samples 9-15 and 628-636. Using laboratory and on-orbit measurements from these vignetted detector array columns a scattered light correction function has been developed to estimate the scattered light based upon the signal distribution in the illuminated portion of the array. This correction is applied to the image on a line by line based to compensate for the scattered light in the DSS image.

Laboratory flat field correction: When illuminated by a uniform light source there is some variability in the cross-track radiometric response. To correct for this laboratory measurement were acquired across the field of view from a uniform source. Figure 2-11 shows the laboratory flat field image. The flat field is 640 spatial by 260 spectral values for Target Mode and 320 spatial by 86 spectral values for Global Mode. The flat field is multiplied by the DSS image to compensate for this radiometric variability in the full system.

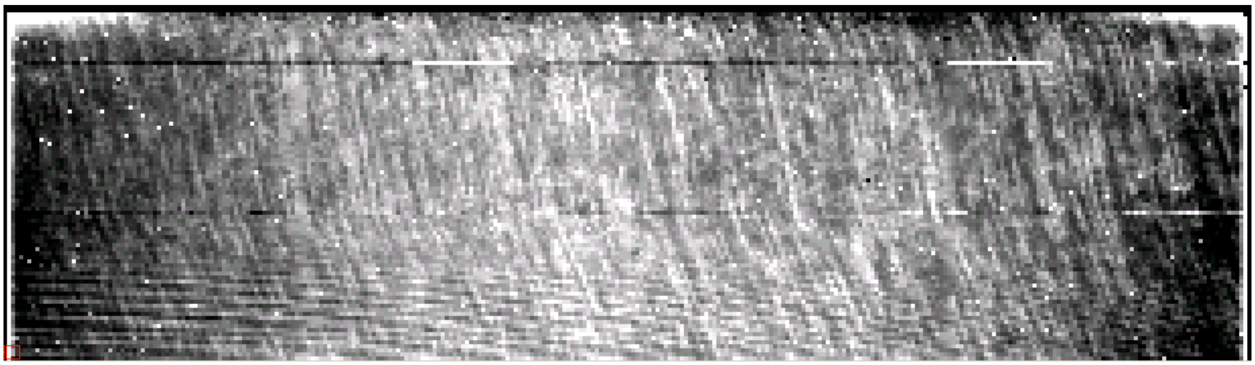


Figure 2-11. Laboratory calculated flat field image for M^3 Global Mode.

Imaging based flat field correction: Once in orbit around the Moon an assessment of the flight field correction was made through averaging long orbital data sets. Analysis of these image based flat field images showed that an additional flat field correction was required for the on orbit measurements of M^3. Image based flat field correction values were derived by averaging the longest on orbit data sets and then dividing by the cross-track average value. This simple approach also removed the cross-track photometric signal. To retain the cross-track photometry a two dimensional plane is fit to the image based flat field and retained in the image based flat field correction factor. To suppress the impact of features on the lunar surface in the image based flat field a smoothed spectral average of the function is divided out in a final step. Figure 2-12 shows one of the image based flight field correction data sets. The DSS image is multiplied by image based flat field to suppress this radiometric response variability that is not compensated by the laboratory flat field.

Figure 2-12. Image based flat field.

Radiometric calibration: Following the full suite of pre-processing steps described, the DSS image is multiplied by the laboratory traced radiometric calibration coefficients that convert DN of the DSS image to units of radiance (W/m^2/um/sr). The laboratory spectral calibration values are also associated with the calibrated image in this final step. Figure 2-13 show an example the input DSS image and DN per channel spectrum. Figure 2-14 shows the output image and radiance per wavelength spectrum of the calibrated image.

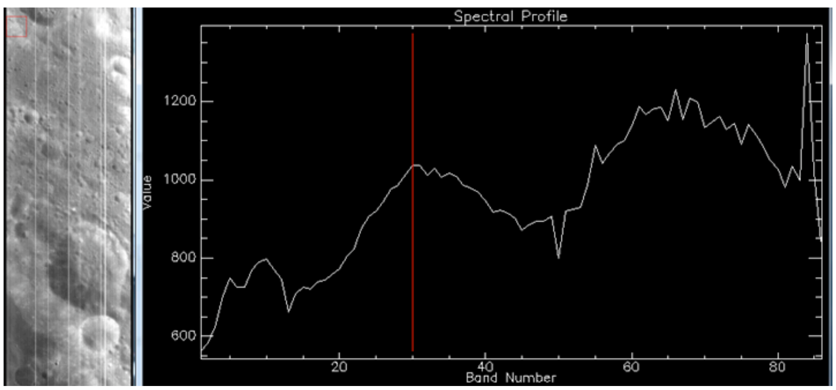


Figure 2-13. Input raw image and data from the M^3 instrument.

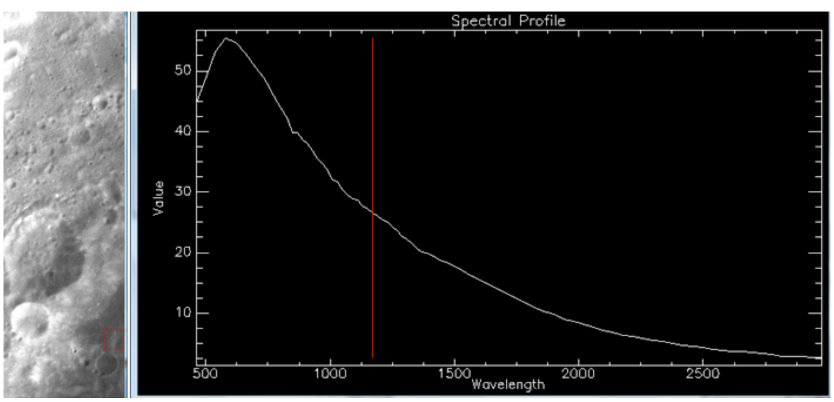


Figure 2-14. Output image and spectrum from the M^3 calibration processing pipeline.

The result of radiometric and spectral calibration is an image cube in units of spectral radiance (W/m^2/μm/sr). Associated calibration files can be found in the CALIB directory of the volume. Dark signal image file, bad detector element maps and image-based flat field files can be found in the EXTRAS directory of the volume.

All validation results and updates of the radiometric and spectral calibration will be reported and published in the journal literature as well as associated documentation of the M^3 PDS archive.

2.5.3.2. Ray Tracing and Pixel Location

The pixel location data for each radiance and reflectance image cube contain 3 parameters. The three parameters are as follows:

1) planetocentric latitude (reported in decimal degrees)
2) longitude (reported in decimal degrees)
3) radius (reported in meters from the Moon center)

The location file is, in essence, a three-band set of “detached backplanes” that match the sample and line spatial extent of the radiance image cube data. No map correction or resampling is applied to the radiance image cube; the file only reports the surface locations of the unadjusted pixel centers.

The pixel location data for each radiance image cube are created by a full four-dimensional ray-tracing subroutine of the Level 1B processing. The spacecraft ephemeris and timing are derived from the respective SPICE SPK and SCLK kernels. Due to problems in the spacecraft attitude data, the attitude for each orbit and the in-flight camera model were derived via a non-linear optimization leveraging image overlaps and ground control derived form LOLA topography. The derived camera model is reported in an IK kernel. The derived per-orbit attitude information is reported as roll, pitch and yaw values for 3each image , relative to an instantaneous orbit-based frame, in each image PDS label. Each pixel is individually ray traced to its center point intersection with the Moon’s surface. The topography of the Moon is represented by NASA’s Lunar Orbiter Laser Altimeter (LOLA) data. The ray tracing models the full complexity of the three dimensions of the spacecraft-camera-Moon model along with the subtle effects of light-time and velocity aberration. As detached backplanes these data can be updated as improved inputs are derived or supplied, without requiring an update for the voluminous radiance image data.

The coordinate system used in the ray tracing and data reporting is the new “Standardized Lunar Coordinate System for the Lunar Reconnaissance Orbiter” (LRO Working Group, 2007). This new lunar coordinate system is being adopted as an international standard and will greatly facilitate the direct integration of data from multiple missions and among international partners. The coordinate system is based on lunar planetocentric coordinates in the Mean Earth/Polar Axis (ME) reference frame. The z-axis is the mean axis of rotation with the positive direction pointing north. The x-axis is the intersection of the Equator and Prime Meridian, as defined by the mean Earth direction. The y-axis completes the frame in a right-handed sense and points in the direction of +90 degrees longitude. Latitude ranges from +90 to -90 from the North Pole to the South Pole. Longitude will be reported as 0 to 360 degrees increasing to the East.

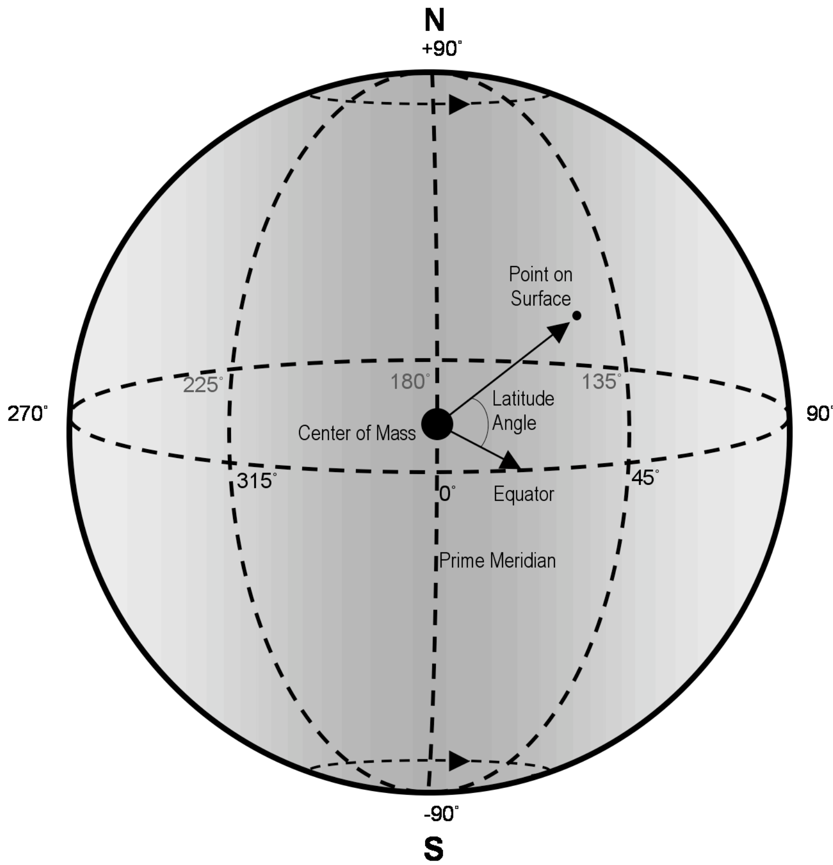


Figure 2-4. Planetocentric coordinates are expressed as right-handed coordinates with the origin at the center of mass of the body (from LRO Working Group, 2007).

The M^3 IGDS shall deliver data to the PDS with planetocentric coordinates in the ME system only in the form of latitude, longitude and radius. These coordinates are fully compliant and in accordance with the PDS Standards Reference (PDS, 2006)

Conversions between the ME system and other systems can be accomplished by using SPICE tools, as developed by the JPL NAIF (NAIF/SPICE, 1996). The ME system is adopted standard system for all lunar missions including Chanrdrayaan-1 and the Lunar Reconnaissance Orbiter. Internal to the Science Team the radius values will be converted to elevations above and below the newly accepted IAU standard lunar radius of 1737.400 kilometers. For mapping purposes that employ these location data, M^3 will use this standard radius and a spherical figure for the selenoid. Conversion from 0-to-360 longitudes to -180-to-180 longitudes is straightforward.

2.5.3.3. Observation Geometry

As a by product of the pixel-location process, the Level 1B processing also provides a suite of ten important parameters that characterize the details of the observation geometry and illumination on a pixel-by-pixel basis. The ten parameters are as follows:

1) to-sun azimuth angle (decimal degrees, clockwise from local north)
2) to-sun zenith angle (incidence angle in decimal degrees, zero at zenith)
3) to-sensor azimuth angle (decimal degrees, clockwise from local north)
4) to-sensor zenith angle (emission angle in decimal degrees, zero at zenith)
5) observation phase angle (decimal degrees, in plane of to-sun and to-sensor rays)
6) to-sun path length (decimal au with scene mean subtracted and noted in PDS label)
7) to-sensor path length (decimal meters)
8) surface slope from DEM (decimal degrees, zero at horizontal)
9) surface aspect from DEM (decimal degrees, clockwise from local north)
10) local cosine i (unitless, cosine of angle between to-sun and local DEM facet normal vectors)

Similar to the pixel-location data, this file is, in essence, a ten-band set of “detached backplanes” that match the sample and line spatial extent of the radiance image cube data. No map correction or resampling is applied to the radiance image cube; the file only reports the observation parameters of the unadjusted pixel centers.

The first seven values at each pixel derive solely from the position of the Sun, Moon and camera at the moment of observation. The final three values at each pixel incorporate parameters from the local lunar topography as described by our triangulated network of the ULCN 2005 (ULCN 2005, 2006), as such they are limited in precision and accuracy by the current lack of detailed knowledge of the lunar topography.

The to-sun and to-sensor angles are measured in a local topocentric frame (east, north, up axes). The azimuth angles are measured according to convention, but contrary to the local frame axes, in a positive manner clockwise from North (0 to 360 degrees). The zenith angles (incidence and emission) are measured relative to the local vertical z-axis of the topocentric frame. The phase angle is measured in the plane of the to-sun and to-sensor vectors. Path lengths are determined using light time correction and reported on a per-pixel basis. The to-sun path length is reported as the deviations from the scene mean to preserve precision. This scene mean value is noted in the PDS label by the keyword SOLAR_DISTANCE.

The surface slope and aspect are determined by the facet of the triangulated topographic network based on the ULCN. The final value, local cosine of the incidence angle, is measured by calculating the angle between the local topographic facet normal vector and the to-sun vector.

The values, reported on a per pixel basis, can be used in subsequent product generation for photometric and radiometric corrections and analyses of the radiance image data.

2.5.3.4. Observation Timing

The timing data consists of the mid-time for each image frame and are derived by decoding the spacecraft timing data, as supplied in the SPICE SCLK kernels, and then converting them from Ephemeris Time to UTC and Decimal Day of Year.

2.5.4. Level 2 Processing

This section presents the preliminary plan for Level 2 processing; it is subject to change.

Level 2 processing involves converting the at-sensor radiance data to reflectance (I/F, applying an Apollo 16 normalization factor and a photometric correction, then normalizing by a wavelength-independent scaling factor such that 100% reflectance is stored as the signed integer value 30000.

2.5.4.1. Photometrically-Corrected Spectral Reflectance Calibration

The baseline inputs and calibration equation for Level 2 processing are given below. This calibration is validated with early measurement of known targets on the moon.

Inputs for the Reflectance (I/F) conversion

- At-Sensor Radiance from Level 1B
  - W/(m^2 μm sr) per pixel from RDN.IMG (*L1B.LBL)
  - W/(m^2 μm sr) per pixel from *RDN.IMG (*RND.HDR)
- MODTRAN(λ) Solar Spectrum Global or Targeted File
  - Same units as the Level 1B at-sensor radiance (W/m^2 μm sr)
  - Supplied by the science team
- Sun-Moon Distance, d, from Level 1B
  - Value for the scene mean in units of AU supplied by the SOLAR_DISTANCE keyword in *L1B.LBL

- Although the per pixel (SOLAR_DISTANCE) + (To-Sun Path Length in *OBS.IMG) as a double-precision value provides more than 6 decimal places, it approaches the topographic uncertainties and thus is not used by the data pipeline. Only the scene mean distance (above) is used.

Input for the Apollo 16 Correction

- Apollo 16 Normalization Factor, A16(λ), Global or Targeted File
  - λ-dependent
  - Currently no correction is applied (*i.e.*, set to all ones)
  - Supplied by the science team

Inputs for the Photometric Correction

- Geometry Information from Level 1B
  - i = incidence angle in degrees as supplied by the "per pixel to-sun zenith" band in *OBS.IMG
  - e = emission angle in degrees as supplied by the "per pixel to-sensor zenith" band in *OBS.IMG
  - α = phase angle in degrees as supplied by the "per pixel phase" band in *OBS.IMG
- Photometric Correction Factor, cf(α, λ), for Global or Targeted Modes
  - Normalized to Apollo 16 at 30º phase; derived as a phase correction of (Ap.16 at 30º) / (Ap.16 at α).
  - The actual photometric correction factor to be applied, cf(α, λ), is bi-linearly interpreted from a look-up table (global or targeted) of correction factors dependent on α and λ, as supplied by the science team.

Input for the Temperature Correction

- This correction is not needed and is not implemented in the pipeline.

Level 2 Equation

L2 Photometrically-Corrected Reflectance(λ)	Level 2
= { [At-Sensor Radiance(λ) * π] / [Modtran(λ) / d^2] }	I/πF Conversion
* A16(λ)	A16 Normalization
* { cf(α, λ) * (cos(i) + cos(e)) / cos(i) }	Photometric Correction
* { Wavelength-independent scaling factor of 30000. }	Normalize 100% reflectance to signed integer 30000

where λ is the wavelength (global or targeted)

Updates to the baseline equation may be implemented around the middle of the mission then again at the end of the mission after measurements of known targets on the Moon (for example, Apollo 16 and Hyperion) have been analyzed.

All validation results and updates of the reflectance calibration will be reported and published in the journal literature as well as associated documentation of the M^3 PDS archive.

2.5.5. Data Flow

Downlinked M^3 science data and spacecraft navigation data are retrieved by the IGDS at JPL from the International Space Science Data Center (ISSDC) in Bangalore, India. Upon ingestion into the system, the raw science data and navigation data are processed to Level 1B through the Operations Pipeline on a weekly basis (non-real time). Level 1B data products are then forwarded to UMD/ACT for generation of Level 2 data products. After validation, M^3 data products are transferred to the PDS Imaging Node for archiving and distributing. Appendix E contains an overview of M^3 science data flow.

Ground data including calibration files were delivered (“safed”) to the PDS on 19 August, 2009. For flight data, delivery of Level 0 and Level 1B data products to the PDS will occur at 6-month intervals. The first delivery is scheduled for June 2010 and will consist of Level 0 and Level 1B data acquired during Optical Period 1. The second delivery is scheduled for December 2010 and will consist of Level 0 and Level 1B data acquired during Optical Period 2. Separate M^3 archive volumes for all Level 2 data products will be delivered to the PDS Imaging Node in June 2011. Delivery media will consist of external hard drives.

2.5.6. Labeling and Identification

Level 0, Level 1B, and Level 2 data products represent M^3 standard products. Each M^3 data product is stored in a single file.

Each M^3 data product has the following naming convention:

M3GYYYYMMDDTHHMMSS_VNN_PT.EXT

Or

M3TYYYYMMDDTHHMMSS_VNN_PT.EXT

M3: The instrument.

G or T: The imaging mode; G for global mode and T for target mode.

YYYY: The year of the time stamp from the first image frame of the image cube.

MM: The month of the time stamp from the first image frame of the image cube.

DD: The day of the time stamp from the first frame of the image cube.

T: A single character string that precedes the UTC time of the time stamp from the first frame of the image cube.

HH: The hour in UTC of the time stamp from the first frame of the image cube.

MM: The minute within the hour in UTC of the time stamp from the first frame of the image cube.

SS: The second within the minute in UTC of the time stamp from the first frame of the image cube.

VNN: The version number of the product.

PT: The type of data product:

L0 = Level 0

L1B = Level 1B

L2 = Level 2

RDN = Spectral Radiance data

LOC = Pixel-located data

OBS = Observation geometry data

TIM = Observation timing data

RFL = Spectral Reflectance data

EXT: The file name extension:

IMG = Image object

HDR = Detached header file

LBL = Detached label file

TXT = ASCII text file

TAB = ASCII data table

All fields must occupy the allotted number of characters. Thus, if fewer digits are required to express a number than are allotted, the convention fills the unneeded spaces with leading zeroes.

2.6. Standards Used in Generating Data Products

2.6.1. PDS Standards

The M^3 data product complies with the PDS standards for file formats and labels, specifically the PDS image and table data objects. File names follow the ISO 9660 Level 2 convention and are no longer than 27.3 characters.

2.6.2. Time Standards

Two time standards are used in M^3 data products:

- Spacecraft time in seconds (PDS keywords SPACECRAFT_CLOCK_START_-COUNT and SPACECRAFT_CLOCK_STOP_COUNT)
- UTC (PDS label keywords START_TIME, STOP_TIME, and PRODUCT_CREATION_TIME)

2.6.3. Coordinate Systems

The coordinate system used is the new "Standardized Lunar Coordinate System for the Lunar Reconnaissance Orbiter" (LRO Working Group, 2008). This new lunar coordinate system has been adopted as an international standard and greatly facilitates the direct integration of data from multiple missions and among international partners. The coordinate system is based on lunar planetocentric coordinates in the Mean Earth/Polar Axis (ME) reference frame. The z-axis is the mean axis of rotation with the positive direction pointing north. The x-axis is the intersection of the Equator and Prime Meridian, as defined by the mean Earth direction. The y-axis completes the frame in a right-handed sense and points in the direction of +90 degrees longitude. Latitude ranges from +90 to -90 form the North Pole to the South Pole. Longitude will be reported as 0 to 360 degrees increasing to the East.

2.7. Data Validation

Basic data validation is performed at the IGDS for M^3 Level 0 – Level 1B data products and at ACT/UMD for M^3 Level 2 data products and consists of the following:

- IGDS and ACT/UMD team members check the data products for conformance to this document and the Archive Volume SIS, and for valid science content.
- Generation of data products and volumes, together with validation are completed within the required validation period of six months from the availability of processing input data.
- Prior to delivery of the products, PDS representatives and other interested parties review a sample product set generated by the IGDS and ACT/UMD and may request changes to the data product set as necessary.

3. Detailed Data Product Specifications

3.1. M^3 Level 0 Data Products

3.1.1. Data Product Structure and Organization

3.1.1.1. L0 Image Cube File Format Overview

M^3 captures data in image frames. Each image frame consists of a 1280 byte image frame header, followed by image data. The format of the image data depends on the instrument mode (global/target - see Table 2-4 for details) at the time the data was collected.

3.1.1.2. Image Frame Header

The image frame header is 1280 bytes long. The first 640 bytes of data in the frame header are in ASCII/text format. Each field is terminated by a semicolon, “;”.

The second 640 bytes of data contain 22 bytes of raw binary data. These 22 bytes contain the time information from the CCSDS header for the particular image frame. The CCSDS time information is then used to calculate the time information contained in the first 640 bytes of ASCII data.

The M^3 image frame header format is included in Table 3-1.

Table 3-1 Image Frame Header

Field Number	Title	Start Char	Stop Char	Description	Format
1	Image Frame Time	0	40	Start time of the image frame.	Absolute time.
2	Semicolon	41	41		“;”
3	File process time	42	85	Time the file was processed	Absolute time.
4	Semicolon	86	86		“;”
5	Mode	87	109	Mode of the instrument when the data was taken.	Instrument Mode.
6	Semicolon	110	110		“;”
7	S/C-Epoch	111	151	Epoch time used by the spacecraft clock.	Absolute Time.
8	Semicolon	152	152		“;”
9	S/C-at-mark	153	195	Spacecraft OBT clock value when the data was taken.	Absolute Time.
10	Semicolon	196	196		“;”
11	M3-RTC-at-mark	197	228	M3 real-time clock value when the S/C-at-mark value is received.	Relative Time.
12	Semicolon	229	229		“;”
13	M3-RTC-at-frame-sync	230	268	M3 real-time clock value when the data	Relative Time.

Field Number	Title	Start Char	Stop Char	Description	Format
				(image frame) was taken.	
14	Unused	269	639	Unused	Blank, " ".
15	Image Frame Time	640	661	Start time of the image frame.	CCSDS time.
29	Unused	662	1279	Unused	Blank, " "

Format Descriptions:

absolute time is UTC clock time. Its format is:

2006-09-22 23:59:59.999; (24 bytes)

relative time is expressed as the number of seconds since spacecraft epoch. The format is:

1234567890.999; (16 bytes)

The calculation of the time information in the first 640 bytes of the Level 0 image frame header is built on the assumed operation of the clocks in a wholly stable manner with fixed tick rates and no drift or unexpected rate issues. To achieve optimized timing for subsequent processing, the Level 1B code develops individual clock conversion models for each image of sufficient length. This per-image modeling accommodates any clock drift or rate changes and provides the best possible frame times for the Level 1B data. As such, the ASCII UTC times in the image frame header may differ from those in the Level 1B data products. The time information in the Level 0 image frame header should be considered deprecated and are only approximate UTC frame times. The per-image optimized calculation used in the Level 1B processing yields the most accurate frame times and are captured in the Observation Timing File products (*TIM.TAB and *TIM.LBL).

The L0 multiple-band image cube has dimensions of sample, line, and channel, where the first channel of each image frame contains the image frame header. This is illustrated in Figure 3-1 and Figure 3-2. The M^3 image cube's size and format depends on the observation mode (global/target).

Figure 3-1. Contents of an M^3 L0 Image Cube File

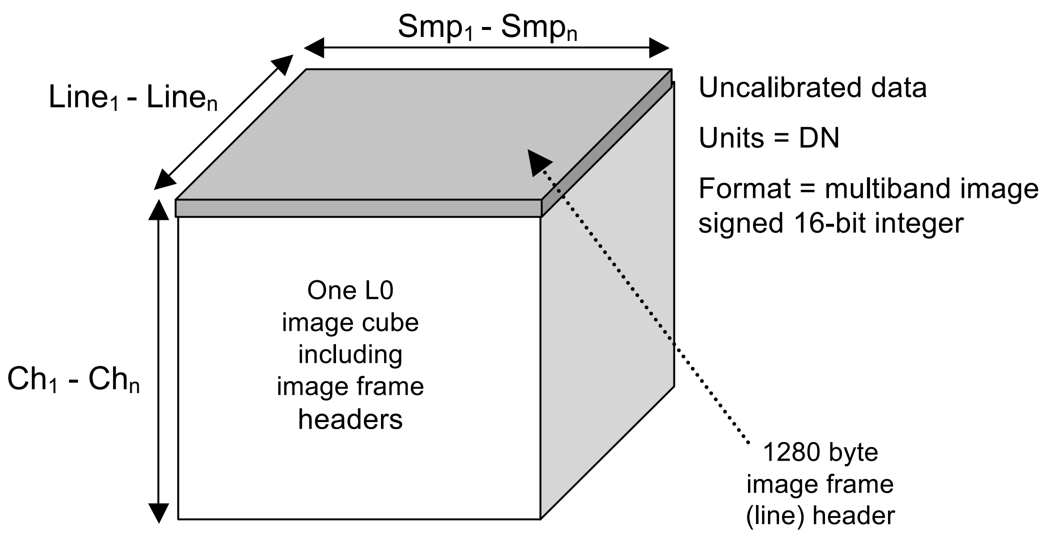
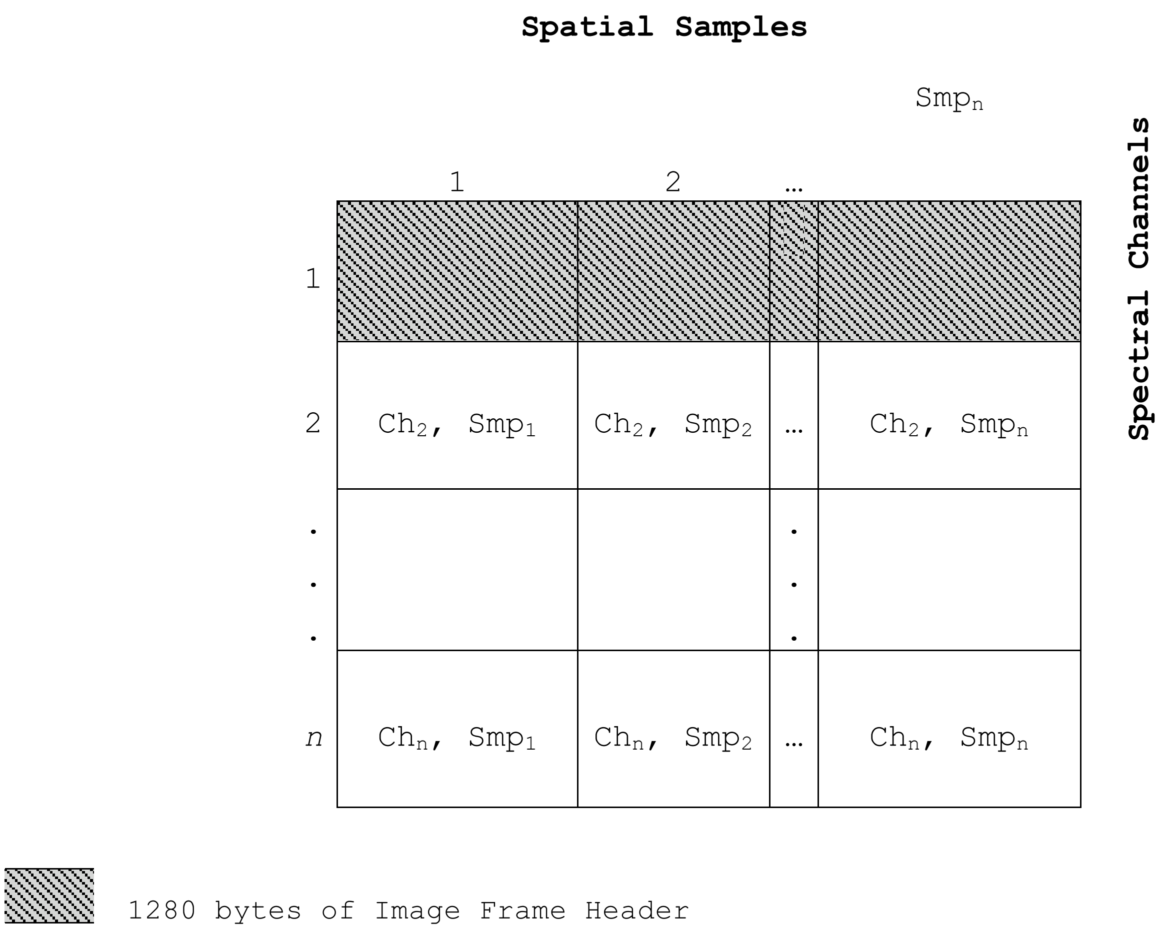


Figure 3-2. Illustration of a Single M^3 L0 Image Frame (Line)



3.1.1.3. L0 Image Cube Format

The format of the M^3 L0 image cube depends on the instrument mode at the time the data was taken. During the transmission and encoding/decoding of the data, some data elements may be lost. Data lost to poor compression or complete packet loss are noted in the *.LOG files located in the EXTRAS directory.

3.1.1.3.1. Target Mode

In target mode, the image cube has the following characteristics:

16-bit signed integer

Little endian

260 spectral channels [Ch]

640 spatial samples [Smp]

N image lines

Band interleaved by line

640 16-bit word image line header [H]

In the line by line file summary below, Ch_xSmp_y identifies a 16-bit signed integer in little endian format.

Ch_1 contains the shortest wavelength and C_{260} contains the longest wavelength.

Smp_1 is located at the left-hand side of the image and Smp_{640} is located at the right-hand side of the image.

$LINE_1$ [$H_1 \ldots H_{1280}$-$Ch_1Smp_1 \ldots Ch_1Smp_{640}$-$Ch_2Smp_1 \ldots Ch_2Smp_{640}$-$Ch_{260}Smp_1 \ldots Ch_{260}Smp_{640}$]

.

.

.

$LINE_N$ [$H_1 \ldots H_{1280}$-$Ch_1Smp_1 \ldots Ch_1Smp_{640}$-$Ch_2Smp_1 \ldots Ch_2Smp_{640}$-$Ch_{260}Smp_1 \ldots Ch_{260}Smp_{640}$]

3.1.1.3.2. Global Mode

In global mode, the image cube has the following characteristics:

16-bit signed integer

Little endian

86 spectral channels

320 spatial samples

N image lines

Band interleaved by line

640 16-bit word image line header

In the line by line file summary below, Ch_xSmp_y identifies a 16-bit signed integer in little endian format.

Ch_1 contains the shortest wavelength and Ch_{86} contains the longest wavelength.

Smp_1 is located at the left-hand side of the image and Smp_{320} is located at the right-hand side of the image.

$LINE_1$ [$H_1 \ldots H_{1280}$-$Ch_1Smp_1 \ldots Ch_1Smp_{320}$-$Ch_2Smp_1 \ldots Ch_2Smp_{320}$-$Ch_{86}Smp_1 \ldots Ch_{86}Smp_{320}$]

.

.

.

$LINE_N$ [$H_1 \ldots H_{1280}$-$Ch_1Smp_1 \ldots Ch_1Smp_{320}$-$Ch_2Smp_1 \ldots Ch_2Smp_{320}$-$Ch_{86}Smp_1 \ldots Ch_{86}Smp_{320}$]

3.1.1.4. L0 Detached Header File Format

Each L0 image cube file will be accompanied by a detached header file. A detached header provides compatibility with ENVI (version 4.4) software. The header file is a separate ASCII text file that contains information ENVI uses to read an image data file. The header file provides the following information:
- The dimensions of the image
- The imbedded header, if present
- The data format
- Other pertinent information

The detached header file will include the following text (see Table 3-3 for a description of the fields):

3.1.1.4.1. Target Mode

```
ENVI
description = {}
samples = 640
```

```
lines = N*
bands = 260
header offset = 0
major frame offsets = {1280, 0}
file type = ENVI
data type = 2
interleave = bil
byte order = 0
```

**N equals the number of image lines of the output file.*

3.1.1.4.2. Global Mode

```
ENVI
description = {}
samples = 320
lines = N*
bands = 86
header offset = 0
major frame offsets = {1280, 0}
file type = ENVI
data type = 2
interleave = bil
byte order = 0
```

**N equals the number of image lines of the output file*

Table 3-3 Detatched ASCII Header Details

Field	Description
description	A character string describing the image or the processing performed.
samples	The number of samples (pixels) per image line for each band.
lines	The number of lines per image for each band.
bands	The number of bands per image file.
header offset	The number of bytes of imbedded header information present in the file. ENVI skips these bytes when reading the file.
major frame offsets	The number of extra bytes to skip at the beginning and ending of the major frame.

Field	Description
`file type`	The ENVI-defined file type, such as a certain data format and processing result.
`data type`	The type of data representation, where 1=8-bit byte; 2=16-bit signed integer; 3=32-bit signed long integer; 4=32-bit floating point; 5=64-bit double-precision floating point; 6=2x32-bit complex, real-imaginary pair of double precision; 9=2x64-bit double-precision complex, real-imaginary pair of double precision; 12=16-bit unsigned integer; 13=32-bit unsigned long integer; 14=64-bit signed long integer; and 15=64-bit unsigned long integer.
`interleave`	Refers to whether the data are formatted as Band Sequential (BSQ), Band Interleaved by Pixel (BIP), or Band Interleaved By Line (BIL).
`byte order`	The order of the bytes in integer, long integer, 64-bit integer, unsigned 64-bit integer, floating point, double precision, and complex data types. Use one of the following: • Byte order=0 (Host (Intel) in the Header Info dialog) is least significant byte first (LSF) data (DEC and MS-DOS systems). • Byte order=1 (Network (IEEE) in the Header Info dialog) is most significant byte first (MSF) data (all other platforms).
`wavelength units`	Text string indicating the wavelength units.
`wavelength`	Lists the center wavelength values of each band in an image. Units should be the same as those used for the fwhm field (described next) and set in the wavelength units parameter.
`fwhm`	Lists full-width-half-maximum (FWHM) values of each band in an image. Units should be the same as those used for wavelength and set in the wavelength units parameter.
`band names`	Allows entry of specific names for each band of an image.

3.1.1.5. L0 Label Description

Each M^3 L0 data product is described by a PDS label stored in a separate text file with an extension ".LBL." A PDS label is object-oriented and describes objects in the data file. The PDS label contains keywords for product identification, along with descriptive information needed to interpret or process the data objects in the file.

PDS labels are written in Object Description Language (ODL). PDS label statements have the form of "keyword = value." Each label statement is terminated with a carriage return character (ASCII 123) and a line feed character (ASCII 10) sequence to allow the label to be read by many operating systems. Pointer statements with the following format are used to indicate the location of data objects:

^object = location

where the carat character (^, also called a pointer) is followed by the name of the specific data object. The location is the name of the file that contains the data object.

The M^3 L0 label is a combined-detached label that describes both the image and detached header file that make up a M^3 L0 data product. An example L0 label is in Appendix A.

3.2. M^3 Level 1B Data Products

3.2.1. Data Product Structure and Organization

3.2.1.1. L1B Spectral Radiance Image Cube File Format Overview

The L1B multiple-band spectral radiance image cube has dimensions of sample, line, and channel (see section 2.4.3.1 for details regarding conversion to spectral radiance). This is illustrated in Figure 3-3 and Figure 3-4. The M^3 spectral radiance image cube's size and format depends on the observation mode (global/target - see Table 2-4 for details).

All M^3 Level 1B products are standardized to remove the different effects of the four possible orbit limb and flight yaw mode combinations: descending/forward; descending/reverse; ascending/forward and ascending/reverse. In ascending limb data the lines/times are reversed, so all Level 1B images have the northernmost image line first. In descending/reverse and ascending/forward modes the samples are reversed, so the first sample is on the west side of the image and do not appear left-right mirrored. In descending/forward no changes in lines or samples are performed; this is the only case that matches the Level 0 data. Refer to the ORBIT_LIMB_DIRECTION and SPACECRAFT_YAW_DIRECTION keywords in the PDS label (*_L1B.LBL – See Appendix B for more details) to reconcile a specific Level 1B image product with the associated Level 0 data.

Figure 3-3. Contents of an M^3 L1B Spectral Radiance Image Cube File

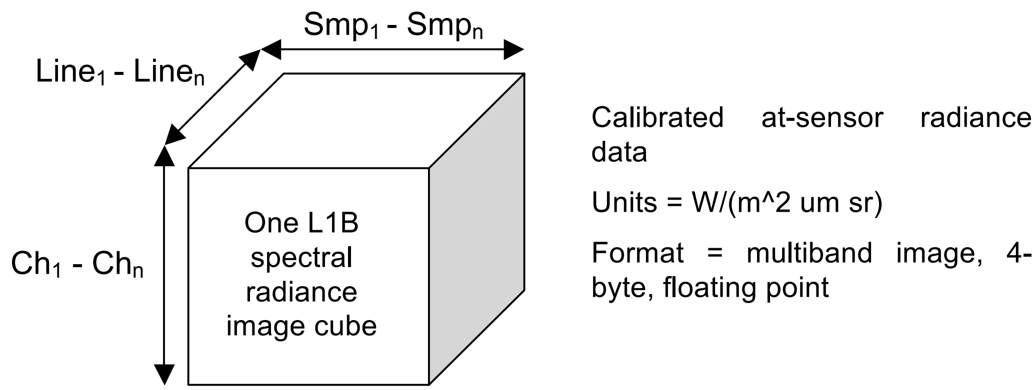


Figure 3-4. Illustration of a Single M^3 L1B Spectral Radiance Image Frame (Line)

Spatial Samples

	1	2	…	Smp_n
1	Ch_1, Smp_1	Ch_1, Smp_1	…	Ch_1, Smp_n
. . .			. . .	
n	Ch_n, Smp_1	Ch_n, Smp_1	…	Ch_n, Smp_n

Spectral Channels

3.2.1.2. L1B Spectral Radiance Image Cube Format

The format of the M^3 Level 1B spectral radiance image cube depends on the instrument mode at the time the data was taken. During the transmission and encoding/decoding of the data, some data elements may be lost. Data lost to poor compression or complete packet loss are noted in the *.LOG files located in the EXTRAS directory.

3.2.1.2.1. Target Mode

In target mode, the spectral radiance image cube has the following characteristics:

32-bit floating point

Little endian

259 spectral channels [Ch]

600 spatial samples [Smp]

N image lines

Band interleaved by line

In the line by line file summary below, Ch_xSmp_y identifies a 32-bit signed floating point in little endian format.

Ch_1 contains the shortest wavelength and C_{259} contains the longest wavelength.

Smp_1 is located at the left-hand side of the image and Smp_{600} is located at the right-hand side of the image.

$LINE_1$ [$Ch_1Smp_1 \ldots Ch_1Smp_{600}$-$Ch_2Smp_1 \ldots Ch_2Smp_{600}$-$Ch_{259}Smp_1 \ldots Ch_{259}Smp_{600}$]

.

.

.

$LINE_N$ [$Ch_1Smp_1 \ldots Ch_1Smp_{600}$-$Ch_2Smp_1 \ldots Ch_2Smp_{600}$-$Ch_{259}Smp_1 \ldots Ch_{259}Smp_{600}$]

3.2.1.2.2. *Global Mode*

In global mode, the spectral radiance image cube has the following characteristics:

32-bit floating point

Little endian

85 spectral channels

304 spatial samples

N image lines

Band interleaved by line

In the line by line file summary below, Ch_xSmp_y identifies a 32-bit floating point in little endian format.

Ch_1 contains the shortest wavelength and Ch_{85} contains the longest wavelength.

Smp_1 is located at the left-hand side of the image and Smp_{300} is located at the right-hand side of the image.

$LINE_1$ [$Ch_1Smp_1 \ldots Ch_1Smp_{300}$-$Ch_2Smp_1 \ldots Ch_2Smp_{300}$-$Ch_{84}Smp_1 \ldots Ch_{85}Smp_{300}$]

.

.

.

$LINE_N$ [$Ch_1Smp_1 \ldots Ch_1Smp_{300}$-$Ch_2Smp_1 \ldots Ch_2Smp_{300}$-$Ch_{84}Smp_1 \ldots Ch_{85}Smp_{300}$]

3.2.1.3. L1B Spectral Radiance Image Cube Detached Header File Format

Each L1B spectral radiance image cube file will be accompanied by a detached header file. A detached header provides compatibility with ENVI (version 4.4) software. The header file is a separate ASCII text file that contains information ENVI uses to read an image data file.

The header file provides the following information:
• The dimensions of the image
• The imbedded header, if present
• The data format
• Other pertinent information

The detached header file will include the following text (see Table 3-3 for a description of the fields):

3.2.1.3.1. Target Mode

```
ENVI
description = {}
samples = 600
lines = N*
bands = 259
header offset = 0
file type = ENVI
data type = 4
interleave = bil
byte order = 0
wavelength = {}
fwhm = {}
```

**N equals the number of image lines of the output file.*

3.2.1.3.2. Global Mode

```
ENVI
description = {}
samples = 304
lines = N*
bands = 85
header offset = 0
file type = ENVI
data type = 4
interleave = bil
byte order = 0
wavelength = {}
fwhm = {}
```

**N equals the number of image lines of the output file*

3.2.1.4. Level 1B Spectral Radiance Image Cube Label Description

A spectral radiance image cube label (*_L1B.LBL) is detached and points to the following L1B data products:

- the single multi-band image (*_RDN.IMG) and its respective detached header file (*_RDN.HDR),
- the pixel location data (*_LOC.IMG) and its respective detached header file (*_LOC.HDR),
- the observation geometry data (*_OBS.IMG) and its respective detached header file (*_OBS.HDR),
- the UTC timing data (*_TIM.TAB)

An example Level 1B spectral radiance image cube label is located in Appendix B.

3.2.1.5. Pixel Location File Format

The pixel location data for each image are stored in a three-band, band-interleaved-by-line, binary file of double precision 8-byte values, in little-endian byte order. The three bands of the file, in order, are as follows:

1) longitude (reported in decimal degrees)
2) planetocentric latitude (reported in decimal degrees)
3) radius (reported in meters from the Moon center)

There are no embedded headers or other data in the file. Each location file will be accompanied by a detached header file. A detached header provides compatibility with ENVI software. The location file is, in essence, a three-band set of “detached backplanes” that match the sample and line spatial extent of the spectral radiance image cube data. No map correction or resampling is applied to the radiance image cube; the file only reports the surface locations of the unadjusted pixel centers.

3.2.1.6. Pixel Location Detached Header File Format

Each location image cube file will be accompanied by a detached header file. A detached header provides compatibility with ENVI software. The header file is a separate ASCII text file that contains information ENVI uses to read an image data file.

The header file provides the following information:
- The dimensions of the image
- The imbedded header, if present
- The data format
- Other pertinent information

The detached header file will include the following text (see Table 3-3 for a description of the fields):

3.2.1.6.1. Target Mode

```
ENVI
description = {}
samples = 600
lines = N*
bands = 3
header offset = 0
file type = ENVI
data type = 5
interleave = bil
byte order = 0
wavelength units = Unknown
band names = {longitude (deg), latitude (deg), elevation (m
above 1738km)}
```

**N equals the number of image lines of the output file.*

3.2.1.6.2. Global Mode

```
ENVI
description = {}
samples = 304
lines = N*
bands = 3
header offset = 0
```

```
file type = ENVI
data type = 5
interleave = bil
byte order = 0
wavelength units = Unknown
band names = {longitude (deg), latitude (deg), radius)}
```

**N equals the number of image lines of the output file*

3.2.1.7. Observation Geometry File Format

The observation geometry data for each image are provided in a ten-band, band-interleaved-by-line, binary file of single precision 4-byte values, in little-endian byte order. The ten bands of the file, in order, are as follows:

1) to-sun azimuth angle (decimal degrees, clockwise from local north)
2) to-sun zenith angle (decimal degrees, zero at zenith)
3) to-sensor azimuth angle (decimal degrees, clockwise from local north)
4) to-sensor zenith angle (decimal degrees, zero at zenith)
5) observation phase angle (decimal degrees, in plane of to-sun and to-sensor rays)
6) to-sun path length (decimal au with scene mean subtracted and noted in PDS label)
7) to-sensor path length (decimal meters)
8) surface slope from DEM (decimal degrees, zero at horizontal)
9) surface aspect from DEM (decimal degrees, clockwise from local north)
10) local cosine i (unitless, cosine of angle between to-sun and local DEM facet normal vectors)

Similar to the location data, these files are, in essence, ten-band set of “detached backplanes” that match the sample and line spatial extent of the spectral radiance image cube data. No map correction or resampling is applied to the radiance image cube; the file only reports the observation parameters of the unadjusted pixel centers.

3.2.1.8. Observation Geometry Detached Header File Format

Each observation geometry data file will be accompanied by a detached header file. A detached header provides compatibility with ENVI software.

The detached header file is an ASCII file will include the following text:

3.2.1.8.1. Target Mode

```
ENVI
description = {
M3 Level 1B Observation Parameters (scene mean To-Sun Path
Length subtracted from Band 6 (au):1.013437249601 IAU au defined
as 149597870691 meters}
samples = 600
lines = N*
bands = 10
header offset = 0
file type = ENVI Standard
data type = 4
interleave = bil
byte order = 0
wavelength units = Unknown
band names = {
To-Sun Azimuth (deg), To-Sun Zenith (deg), To-M3 Azimuth(deg),
To-M3 Zenith (deg), Phase (deg), To-Sun Path Length (au-
1.013437249601), To-M3 Path Length (m), Facet Slope (deg), Facet
Aspect (deg), Facet Cos(i) (unitless)}
```

**N equals the number of image lines of the output file.*

3.2.1.8.2. Global Mode

```
ENVI
description = {
M3 Level 1B Observation Parameters (scene mean To-Sun Path
Length subtracted from Band 6 (au):1.013437249601 IAU au defined
as 149597870691 meters)}
samples = 304
lines = N*
bands = 10
header offset = 0
file type = ENVI Standard
data type = 4
interleave = bil
byte order = 0
wavelength units = Unknown
band names = {
To-Sun Azimuth (deg), To-Sun Zenith (deg), To-M3 Azimuth(deg),
To-M3 Zenith (deg), Phase (deg), To-Sun Path Length (au-
1.013437249601), To-M3 Path Length (m), Facet Slope (deg), Facet
Aspect (deg), Facet Cos(i) (unitless)}
```

**N equals the number of image lines of the output file*

3.2.1.9. Observation Timing File Format

The timing file (*TIM.TAB) is an ASCII file with four columns of data. The first column lists the line number of the multiple-band spectral radiance image cube (*RDN.IMG). The second column lists the corresponding UTC time for the middle of the integration period for each spectral radiance image cube line or major frame of the data and is expressed as:

YYYY-MM-DDTHH:MM:SS.SSSSSS.

The third column lists Year reference of Decimal Day of Year (DDOY) as extracted from the earliest time of each spectral radiance image cube line expressed as: YYYY.

The fourth column lists DDOY which represents the number of days elapsed since 00:00 UTC of January 1 of the year associated with the time stamp of the first image line. The DDOY format is as follows: DDD.dddddddddddd where DDD represents the integer number of days and dddddddddddd represent the fractional part of the day of year value.

Note that the times listed in the timing file may differ from those reported in the L0 image frame header. See Section 3.1.1.2 for details.

3.3. M^3 Level 2 Data Products

This section presents t preliminary plan for Level 2 processing; it is subject to change.

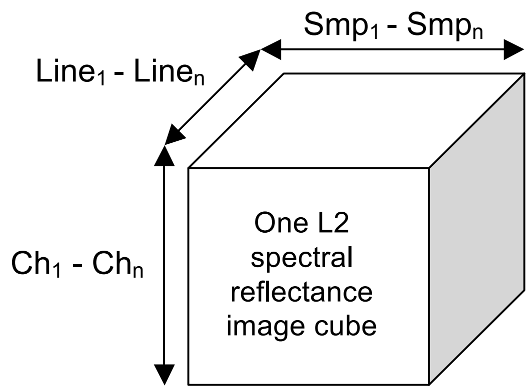
3.3.1. Data Product Structure and Organization

3.3.1.1. L2 Spectral Reflectance Image Cube File Format Overview

The L2 multiple-band spectral reflectance image cube has the same dimensions of sample, line, and channel as the Level 1B spectral radiance image cube from which it was derived. This is illustrated in Figures 3-5 and 3-6. As with Level 1B, the size and format of the M^3 spectral reflectance image cube depends on the observation (global/target – see Table 2-4 for details).

Because Level 2 products are generated from Level 1B, these reflectance data are inherently standardized to remove the different effects of the four possible orbit limb and flight yaw mode combinations: descending/forward; descending/reverse; ascending/forward and ascending/reverse. In ascending limb data the lines/times are reversed, so all Level 2 images have the northernmost image line first. In descending/reverse and ascending/forward modes the samples are reversed, so the first sample is on the west side of the image and do not appear left-right mirrored. In descending/forward no changes in lines or samples are performed; this is the only case that matches the Level 0 data. Refer to the ORBIT_LIMB_DIRECTION and SPACECRAFT_YAW_DIRECTION keywords in the PDS label (*_L2.LBL - See Appendix C for more details) to reconcile a specific Level 2 image product with the associated Level 0 data.

Figure 3-5. Contents of an M^3 L2 Spectral Reflectance Image Cube File



Calibrated at-sensor reflectance data

Unitless

Format = multiband image, 32-bit floating point numbers from 0 to 1 where 1.0 represents 100% reflectance.

Figure 3-4. Illustration of a Single M^3 L2 Spectral Reflectance Image Frame (Line)

Spatial Samples

Spectral Channels

	1	2	...	Smp_n
1	Ch_1, Smp_1	Ch_1, Smp_1	...	Ch_1, Smp_n
. . .			. . .	
n	Ch_n, Smp_1	Ch_n, Smp_1	...	Ch_n, Smp_n

3.3.1.2. L2 Spectral Reflectance Image Cube Format

As with a Level 1B product, the format of the M^3 Level 2 spectral reflectance image cube depends on the instrument mode (global/target - see Table 2-4 for details) at the time the data was taken. During the transmission and encoding/decoding of the Level 0/1B products, some data elements may be lost. Data lost to poor compression or complete packet loss are noted in the *.LOG files located in the EXTRAS directory.

3.3.1.2.1. Target Mode

In target mode, the spectral reflectance image cube has the following characteristics:

32-bit floating point numbers where 1.0 represents 100% reflectance

Little endian

259 spectral channels [Ch]

600 spatial samples [Smp]

N image lines

Band interleaved by line

In the line by line file summary below, Ch_xSmp_y identifies a 32-bit floating point numbers in little endian format.

Ch_1 contains the shortest wavelength and C_{259} contains the longest wavelength.

Smp_1 is located at the left-hand side of the image and Smp_{600} is located at the right-hand side of the image.

$LINE_1$ [$Ch_1Smp_1 \ldots Ch_1Smp_{600}$-$Ch_2Smp_1 \ldots Ch_2Smp_{600}$-$Ch_{259}Smp_1 \ldots Ch_{259}Smp_{600}$]

.

.

.

$LINE_N$ [$Ch_1Smp_1 \ldots Ch_1Smp_{600}$-$Ch_2Smp_1 \ldots Ch_2Smp_{600}$-$Ch_{259}Smp_1 \ldots Ch_{259}Smp_{600}$]

3.3.1.2.2. Global Mode

In global mode, the spectral reflectance image cube has the following characteristics:

32-bit floating point numbers where 1.0 represents 100% reflectance Little endian

85 spectral channels

304 spatial samples

N image lines

Band interleaved by line

In the line by line file summary below, Ch_xSmp_y identifies a 32-bit floating point numbers in little endian format.

Ch_1 contains the shortest wavelength and Ch_{85} contains the longest wavelength.

Smp_1 is located at the left-hand side of the image and Smp_{300} is located at the right-hand side of the image.

$LINE_1$ [$Ch_1Smp_1 \ldots Ch_1Smp_{300}$-$Ch_2Smp_1 \ldots Ch_2Smp_{300}$-$Ch_{85}Smp_1 \ldots Ch_{85}Smp_{300}$]

.

.

.

$LINE_N$ [$Ch_1Smp_1 \ldots Ch_1Smp_{300}$-$Ch_2Smp_1 \ldots Ch_2Smp_{300}$-$Ch_{85}Smp_1 \ldots Ch_{85}Smp_{300}$]

3.3.1.3. L2 Spectral Reflectance Image Cube Detached Header File Format

Each L2 spectral reflectance image cube file will be accompanied by a detached header file. A detached header provides compatibility with ENVI (version 4.4) software. The header file is a separate ASCII text file that contains information ENVI uses to read an image data file.

The header file provides the following information:
• The dimensions of the image
• The imbedded header, if present
• The data format
• Other pertinent information

The detached header file will include the following text (see Table 3-3 for a description of the fields):

3.3.1.3.1. Target Mode

```
ENVI
description = {}
samples = 600
lines = N*
bands = 259
header offset = 0
file type = ENVI
data type = 4
interleave = bil
byte order = 0
wavelength = {}
fwhm = {}
```

**N equals the number of image lines of the output file.*

3.3.1.3.2. Global Mode

```
ENVI
description = {}
samples = 304
lines = N*
bands = 85
header offset = 0
file type = ENVI
data type = 4
interleave = bil
byte order = 0
wavelength = {}
fwhm = {}
```

**N equals the number of image lines of the output file.*

3.3.1.4. Level 2 Spectral Reflectance Image Cube Label Description

A spectral reflectance image cube label (*_L2.LBL) is detached and points to the following L2 data products:

- the single multi-band image (*_RFL.IMG) and its respective detached header file (*_RFL.HDR),

Example Level 2 spectral radiance image cube label is in Appendix C. For location, the observation geometry, and timing information, users must refer to the L1B data products.

4. Applicable Software

4.1. Utility Programs

The M^3 team uses the commercial software packages ENVI and IDL to display and analyze M^3 data products.. ENVI and IDL are distributed by ITT Visual Information Solutions (VIS) and are available at http://www.ittvis.com/. ITT VIS provides a free tool, ENVI Freelook, which allows for basic image viewing. You can download ENVI Freelook software here, http://www.ittvis.com/Downloads/ProductDownloads.aspx. In addition, PDS' NASAView Image Display Software can also be used for basic image viewing: http://pds.nasa.gov/tools/nasa-view.shtml. Nevertheless, the data are in no way in any proprietary format. Instead they are arranged as simply and as openly as possible. The provision of both ENVI and PDS labels will guarantee the data will be readily accessible to the widest possible audience.

4.2. Applicable PDS Software Tools

The M^3 team uses no PDS software to view, manipulate or process the data. However, the images are stored and labeled using the PDS IMAGE standard structure and any tool that understands that structure should be able to view them.

Appendix A Example L0 Data Product PDS Label

```
PDS_VERSION_ID                  = PDS3
LABEL_REVISION_NOTE             = "2009-01-16, S. Lundeen"
DATA_SET_ID                     = "CH1-ORB-L-M3-2-L0-RAW-V1.0"
PRODUCT_ID                      = "M3G20090213T234813_V01_L0"
RECORD_TYPE                     = UNDEFINED

MISSION_ID                      = "CH1"
MISSION_NAME                    = "CHANDRAYAAN-1"
INSTRUMENT_HOST_ID              = "CH1-ORB"
INSTRUMENT_HOST_NAME            = "CHANDRAYAAN-1 ORBITER"
INSTRUMENT_NAME                 = "MOON MINERALOGY MAPPER"
INSTRUMENT_ID                   = M3
TARGET_NAME                     = "MOON"
TARGET_TYPE                     = "SATELLITE"
MISSION_PHASE_NAME              = "PRIMARY MISSION"
PRODUCT_TYPE                    = RAW_IMAGE
PRODUCT_CREATION_TIME           = 2009-06-18T15:52:44
START_TIME                      = 2009-02-13T23:48:13
STOP_TIME                       = 2009-02-14T00:09:03
SPACECRAFT_CLOCK_START_COUNT    = "6/863469.725"
SPACECRAFT_CLOCK_STOP_COUNT     = "6/864719.434"
ORBIT_NUMBER                    = 01179
PRODUCT_VERSION_TYPE            = "PRELIMINARY"

PRODUCER_INSTITUTION_NAME       = "JET PROPULSION LABORATORY"
SOFTWARE_NAME                   = "m3_igds_l0_v18.pl"
SOFTWARE_VERSION_ID             = "18"
DESCRIPTION                     = "M3 Level 0 data product which consists  of
raw science data, reassembled into time-sequenced data in units of digital
numbers."

/* Level 0 Image Instrument and Observation Parameters */

INSTRUMENT_MODE_ID              = "GLOBAL"
DETECTOR_TEMPERATURE            = 146.97
CH1:SWATH_WIDTH                 = 320 <PIXELS>
CH1:SWATH_LENGTH                = 12282 <LINES>

/* Description of Level 0 IMAGE file */

OBJECT          = L0_FILE
  ^L0_IMAGE     = "M3G20090213T234813_V01_L0.IMG"
  RECORD_TYPE   = FIXED_LENGTH
  RECORD_BYTES  = 55040
  FILE_RECORDS  = 12282

  OBJECT                      = L0_IMAGE
    LINES                     = 12282
    LINE_SAMPLES              = 320
    SAMPLE_TYPE               = LSB_INTEGER
    SAMPLE_BITS               = 16
    UNIT                      = "DN"
    BANDS                     = 86
    BAND_STORAGE_TYPE         = LINE_INTERLEAVED
    LINE_DISPLAY_DIRECTION    = DOWN
```

```
    SAMPLE_DISPLAY_DIRECTION = RIGHT
  END_OBJECT                 = L0_IMAGE

END_OBJECT = L0_FILE

/* Description of Level 0 HEADER file */

OBJECT             = L0_HDR_FILE
  ^L0_ENVI_HEADER  = "M3G20090213T234813_V01_L0.HDR"
  RECORD_TYPE      = VARIABLE_LENGTH
  FILE_RECORDS     = 11

  OBJECT               = L0_ENVI_HEADER
    INTERCHANGE_FORMAT = "ASCII"
    BYTES              = 306
    HEADER_TYPE        = ENVI
    DESCRIPTION        = "Header file for compatibility with the commercial
                          software package ENVI."
  END_OBJECT           = L0_ENVI_HEADER

END_OBJECT = L0_HDR_FILE

END
```

Appendix B Example L1B Data Product PDS Label

```
PDS_VERSION_ID                  = PDS3
LABEL_REVISION_NOTE             = "2009-01-26, S. Lundeen"
DATA_SET_ID                     = "CH1-ORB-L-M3-4-L1B-RADIANCE-V1.0"
PRODUCT_ID                      = "M3G20090213T234813_V01_RDN"
RECORD_TYPE                     = UNDEFINED

MISSION_ID                      = "CH1"
MISSION_NAME                    = "CHANDRAYAAN-1"
INSTRUMENT_HOST_ID              = "CH1-ORB"
INSTRUMENT_HOST_NAME            = "CHANDRAYAAN-1 ORBITER"
INSTRUMENT_NAME                 = "MOON MINERALOGY MAPPER"
INSTRUMENT_ID                   = M3
TARGET_NAME                     = "MOON"
TARGET_TYPE                     = "SATELLITE"
MISSION_PHASE_NAME              = "PRIMARY MISSION"
PRODUCT_TYPE                    = CALIBRATED_IMAGE
PRODUCT_CREATION_TIME           = 2008-11-26T00:30:28
START_TIME                      = 2009-02-13T23:48:13
STOP_TIME                       = 2009-02-14T00:09:03
SPACECRAFT_CLOCK_START_COUNT    = "6/863469.725"
SPACECRAFT_CLOCK_STOP_COUNT     = "6/864719.434"
ORBIT_NUMBER                    =  01179
PRODUCT_VERSION_TYPE            = "PRELIMINARY"

PRODUCER_INSTITUTION_NAME       = "JET PROPULSION LABORATORY"
SOFTWARE_NAME                   = "m3g_l1b_v04.exe"
SOFTWARE_VERSION_ID             = "04"
DESCRIPTION                     = "M3 Level 1B data product which contains
selenolocated, radiometrically-calibrated data."

/* Calibrated Image Instrument and Observation Parameters */

SOLAR_DISTANCE                  = 0.988909861158 <AU>
INSTRUMENT_MODE_ID              = "GLOBAL"
DETECTOR_TEMPERATURE            = 146.97
CH1:SWATH_WIDTH                 = 304 <PIXELS>
CH1:SWATH_LENGTH                = 12282 <LINES>
CH1:SPACECRAFT_YAW_DIRECTION    = "REVERSE"
CH1:ORBIT_LIMB_DIRECTION        = "DESCENDING"
SPACECRAFT_ORIENTATION          = (0.181941818404,0.909397345221,
                                   180.659036611184)

NOTE                            = "This Level 1B label describes seven
                                       data files:
  1. A multiple-band image file containing radiance-calibrated data,
  2. An associated ASCII ENVI header file for the radiance-calibrated data,
  3. A multiple-band image file containing selenolocation data,
  4. An associated ASCII ENVI header file for the selenolocation data,
  5. A multiple-band image file containing observation geometry data,
  6. An associated ASCII ENVI header file for the observation geometry data,
  7. An ASCII file containing timing information for each image line.

  All M3 Level 1B products are standardized to remove the different effects
  of the four possible orbit limb and
  flight yaw mode combinations:
```

```
1. descending/forward,
  2. descending/reverse,
  3. ascending/forward,
  4. ascending/reverse.
  In ascending limb data the lines/times are reversed, so all Level 1B images
  have the northernmost image line first.
  In descending/reverse and ascending/forward modes the samples are reversed,
  so the first sample is on the west side of the image and do not appear
  left-right mirrored.
  In descending/forward no changes in lines or samples are performed; this
  is the only case that matches the Level 0 data.
  Refer to the orbit_limb and spacecraft_yaw_mode keywords to reconcile a
  specific Level 1B image product with the associated Level 0 data.


  The SPACECRAFT_ORIENTATION keyword reflect data-derived
  M3 instrument attitude angles (roll, pitch, and yaw respectively) as
  referenced to the CH1 orbit frame.  The ideal nadir attitude (zero roll,
  pitch and yaw) is determined by the to-Moon-center-of-mass unit
  vector (+z), orbit plane normal unit vector (+y) and the unit vector
  that  completes the 3-d frame which is nearly coincident with CH1
  velocity (+x). These attitude angles were derived through image
  optimization using LOLA topography data and M3-to-M3 image overlap matching,
  as the provided CH1 attitude data were not capable of producing a stable
  and accurate result. The roll, pitch and yaw angles are in degrees and
  positive for a right-handed rotation about the specified axes: roll around
  +x, pitch around +y and yaw around +z. The minimum and maximum values for
  the roll, pitch, and yaw as captured by the SPACECRAFT_ORIENTATION keyword
  are -180 to 180."

/* Spectral calibration parameters and radiometric gain factor data */

CH1:SPECTRAL_CALIBRATION_FILE_NAME      = "M3G20081211_RDN_SPC.TAB"
CH1:RAD_GAIN_FACTOR_FILE_NAME           = "M3G20081211_RDN_GAIN.TAB"
CH1:GLOBAL_BANDPASS_FILE_NAME           = "M3G20081211_RDN_BPF.IMG"

/* Description of Radiance-corrected image file */

OBJECT          = RDN_FILE
  ^RDN_IMAGE    = "M3G20090213T234813_V01_RDN.IMG"
  RECORD_TYPE   = FIXED_LENGTH
  RECORD_BYTES  = 102000
  FILE_RECORDS  = 12282

  OBJECT                     = RDN_IMAGE
    LINES                    = 12282
    LINE_SAMPLES             = 304
    SAMPLE_TYPE              = PC_REAL
    SAMPLE_BITS              = 32
    UNIT                     = "W/(m^2 um sr)"
    BANDS                    = 85
    BAND_STORAGE_TYPE        = LINE_INTERLEAVED
    LINE_DISPLAY_DIRECTION   = DOWN
    SAMPLE_DISPLAY_DIRECTION = RIGHT
  END_OBJECT                 = RDN_IMAGE
```

```
/* Description of UTC timing data file */

OBJECT          = UTC_FILE
  ^TABLE        = "M3G20090213T234813_V01_TIM.TAB"
  RECORD_TYPE   = FIXED_LENGTH
  RECORD_BYTES  = 57
  FILE_RECORDS  = 12282 /* (same as RDN image) */

  OBJECT                  = UTC_TIME_TABLE
    NAME                  = "UTC OBSERVATION TIMING DATA"
    INTERCHANGE_FORMAT    = "ASCII"
    ROWS                  = 12282 /* (same as RDN image) */
    COLUMNS               = 4
    ROW_BYTES             = 57
    OBJECT                  = COLUMN
      COLUMN_NUMBER       = 1
      NAME                = "LINE NUMBER"
      DATA_TYPE           = ASCII_INTEGER
      START_BYTE          = 1
      BYTES               = 6
      FORMAT              = "I6"
      DESCRIPTION         = "Record number for each RDN image line"
    END_OBJECT              = COLUMN

    OBJECT                  = COLUMN
      COLUMN_NUMBER       = 2
      NAME                = "UTC_TIME"
      DATA_TYPE           = TIME
      START_BYTE          = 8
      BYTES               = 26
      FORMAT              = "A26"
      DESCRIPTION         = "UTC Time for the middle of the integration period
                             for each RDN image line expressed as
                             YYYY-MM-DDTHH:MM:SS.SSSSSS"
    END_OBJECT              = COLUMN

    OBJECT                  = COLUMN
      COLUMN_NUMBER       = 3
      NAME                = "YEAR"
      DATA_TYPE           = CHARACTER
      START_BYTE          = 35
      BYTES               = 4
      FORMAT              = "I4"
      DESCRIPTION         = "Decimal Day of Year (DDOY) Year reference
                             extracted from the earliest time of each RDN
                             image line"
    END_OBJECT              = COLUMN

    OBJECT                  = COLUMN
      COLUMN_NUMBER       = 4
      NAME                = "DDOY"
      DATA_TYPE           = DATE
      START_BYTE          = 40
      BYTES               = 16
      FORMAT              = "F16.12"
```

```
    DESCRIPTION        = "Decimal Day of Year represented as the number of
                          days elapsed since 00:00 UTC of January 1 of the
                          year associated with the time stamp of the first
                          line of the RDN image file. DDOY is expressed
                          using seventeen characters where 1-3 = three
                          characters that contain the integer number of
                          days; 4 = a decimal point; 5-16 = twelve charact-
                          ers after the decimal for the fractional part of
                          the day of year value."
  END_OBJECT             = COLUMN

 END_OBJECT = UTC_TIME_TABLE

END_OBJECT = UTC_FILE

END
```

Appendix C Example L2 Data Product PDS Label

```
PDS_VERSION_ID                   = PDS3
LABEL_REVISION_NOTE              = "2010-05-10 McLaughlin Revised RFL product."
DATA_SET_ID                      = "CH1-ORB-L-M3-4-L2-REFLECTANCE-V1.0"
PRODUCT_ID                       = "M3G20090214T000903_V00_RFL"

MISSION_ID                       = "CH1"
MISSION_NAME                     = "CHANDRAYAAN-1"
INSTRUMENT_HOST_ID               = "CH1-ORB"
INSTRUMENT_HOST_NAME             = "CHANDRAYAAN-1 ORBITER"
INSTRUMENT_NAME                  = "MOON MINERALOGY MAPPER"
INSTRUMENT_ID                    = M3
TARGET_NAME                      = "MOON"
TARGET_TYPE                      = "SATELLITE"
MISSION_PHASE_NAME               = "PRIMARY MISSION"
PRODUCT_TYPE                     = REFLECTANCE_IMAGE
PRODUCT_CREATION_TIME            = 2010-05-10T23:00:00
START_TIME                       = 2009-02-14T00:09:03
STOP_TIME                        = 2009-02-14T00:35:41
SPACECRAFT_CLOCK_START_COUNT     = “6/864671.871"
SPACECRAFT_CLOCK_STOP_COUNT      = "6/866292.771"
ORBIT_NUMBER                     = "01180"
PRODUCT_VERSION_TYPE             = "PRELIMINARY"

PRODUCER_INSTITUTION_NAME        = "APPLIED COHERENT TECHNOLOGIES CORP"
SOFTWARE_NAME                    = "REACT_V01"
SOFTWARE_VERSION_ID              = "01"

DESCRIPTION                      = "M3 Level 2 data product which contains
selenolocated, photometrically corrected, reflectance data.”

/* Calibrated Image Instrument and Observation Parameters */

SOLAR_DISTANCE                   = 0.988903907330 <AU>
INSTRUMENT_MODE_ID               = "GLOBAL"
DETECTOR_TEMPERATURE             = 146.91
CH1:SWATH_WIDTH                  = 300 <PIXELS>
CH1:SWATH_LENGTH                 = 15708 <LINES>
CH1:SPACECRAFT_YAW_DIRECTION     = "REVERSE"
CH1:ORBIT_LIMB_DIRECTION         = "DESCENDING"
NOTE                             = "This Level 2 label describes two data
                                    files:
  1. A multiple-band image file containing reflectance data (unitless), and
  2. An associated ASCII ENVI header file for the reflectance image file.

  Level 2 products are inherently standardized by Level 1B processing that
  removed the different effects of the four possible orbit limb and flight
  yaw mode combinations:
   1. descending/forward,
   2. descending/reverse,
   3. ascending/forward,
   4. ascending/reverse.
```

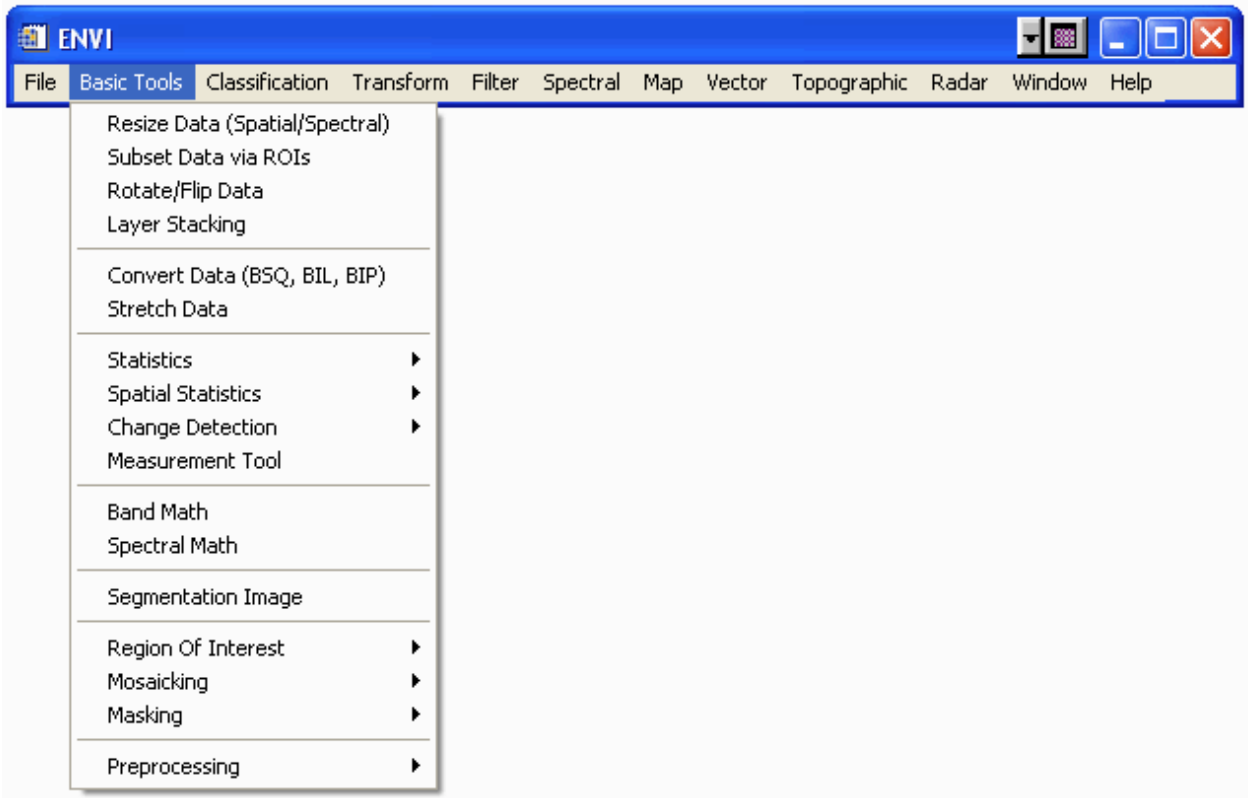
```
  In ascending limb data the lines/times are reversed, so all Level 1B images
  have the northernmost image line first.
  In descending/reverse and ascending/forward modes the samples are reversed,
  so the first sample is on the west side of the image and do not appear
  left-right mirrored.
  In descending/forward no changes in lines or samples are performed; this
  is the only case that matches the Level 0 data.
  refer to the orbit_limb and spacecraft_yaw direction keywords to reconcile
  a specific Level 2 image product with the associated Level 0 data.”


/* Level 1B radiance image, pixel location, observational geometry, and UTC*/
/* timing, and Level 1B calibration files associated with this product.    */

CH1:RAD_IMAGE_FILE_NAME             = "M3G20090214T000903_V00_RDN.IMG"
CH1:LOCATION_FILE_NAME              = "M3G20090214T000903_V00_LOC.IMG"
CH1:OBS_GEOMETRY_FILE_NAME          = "M3G20090214T000903_V00_OBS.IMG"
CH1:TIMING_FILE_NAME                = "M3G20090214T000903_V00_TIM.TAB"
CH1:SPECTRAL_CALIBRATION_FILE_NAME = "M3G20081211_RDN_SPC.TAB"
CH1:RAD_GAIN_FACTOR_FILE_NAME       = "M3G20081211_RDN_GAIN.TAB"
M3:GLOBAL_BANDPASS_FILE_NAME        = "M3G20081211_RDN_BPF.IMG"


/* Calibration files providing the solar spectrum and photometric     */
/* correction factors applied to the Level 1B spectral radiance image */
/* to produce this spectral reflectance image.                        */

CH1:SOLAR_SPECTRUM_FILE_NAME      = "M3G20070912_SOLAR_SPEC_V01.TAB"
CH1:PHOTOM_CORRECTION_FILE_NAME   = "M3G20070912_PHOT_CORR_V01.TAB"
CH1:APOLLO16_CORRECTION_FILE_NAME = "M3G20070912_APOLLO16_CORR.TAB"

/* Description of the reflectance image file, unitless, where a      */
/* stored value of 1.0 represents 100% reflectance.                  */

OBJECT          = RFL_FILE
  ^RFL_IMAGE    = " M3G20090214T000903_V00_RFL.IMG"
  RECORD_TYPE   = FIXED_LENGTH
  RECORD_BYTES  = 102000
  FILE_RECORDS  = 15708

  OBJECT                     = RFL_IMAGE
    LINES                    = 15708
    LINE_SAMPLES             = 300
    SAMPLE_TYPE              = PC_REAL
    SAMPLE_BITS              = 32
    BANDS                    = 85
    BAND_STORAGE_TYPE        = LINE_INTERLEAVED
    LINE_DISPLAY_DIRECTION   = DOWN
    SAMPLE_DISPLAY_DIRECTION = RIGHT
 END_OBJECT                 = RFL_IMAGE

END_OBJECT = RFL_FILE

/* Description of reflectance image header file */
```

```
OBJECT           = RFL_HDR_FILE
  ^ENVI_HEADER   = " M3G20090214T0000903_V00_RFL.HDR"
  RECORD_TYPE    = VARIABLE_LENGTH
  FILE_RECORDS   = 1138

  OBJECT                = RFL_ENVI_HEADER
    INTERCHANGE_FORMAT = "ASCII"
    BYTES              = 20757
    HEADER_TYPE        = ENVI
    DESCRIPTION = "Header file for compatibility with the commercial software
                   package ENVI."
  END_OBJECT = RFL_ENVI_HEADER

END_OBJECT = RFL_HDR_FILE

END
```

Appendix D INSTRUCTION FOR BASIC VIEWING OF AN M^3 L0/L1B/L2 Image Cube File (*.IMG) USING ENVI 4.3

1. When you start ENVI, the ENVI main menu bar appears. You initiate activities in ENVI by using the menus in the ENVI main menu bar.

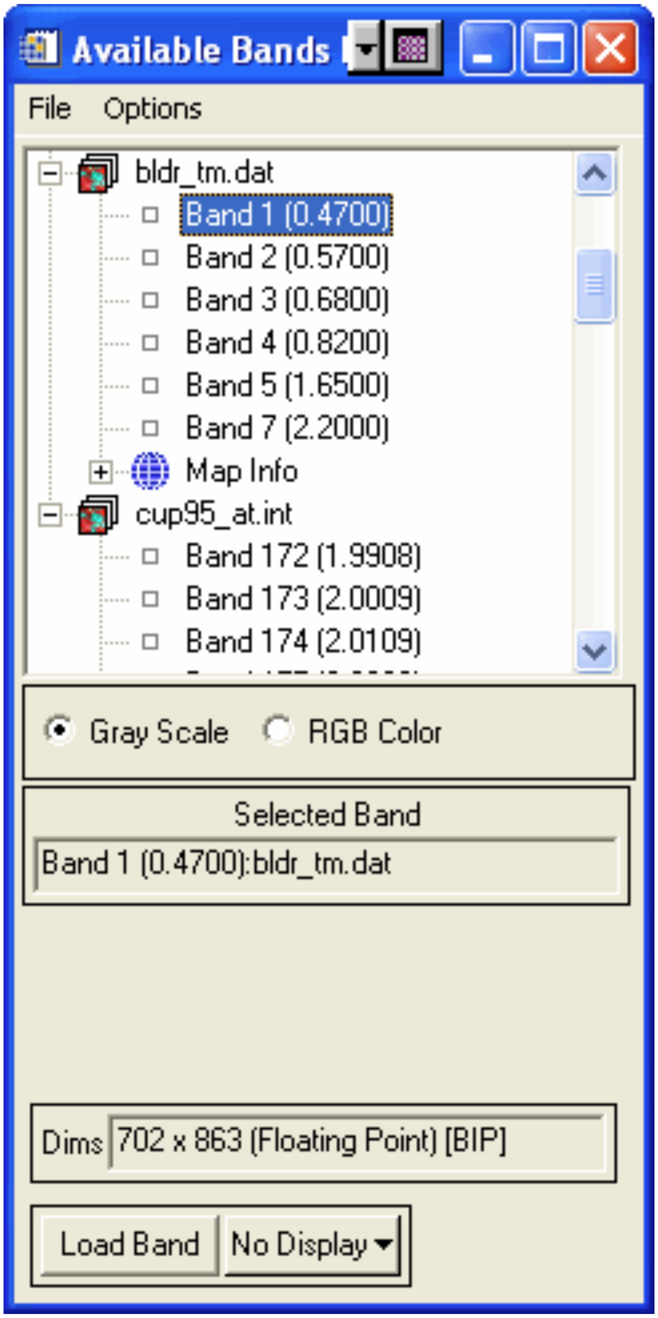
Figure D-1: ENVI Main Menu Bar



2. From the ENVI main menu bar, select **File** → **Open Image File**.
3. In the “Look in:” field, navigate to the appropriate directory containing the *.IMG file you would like to display.
4. Click **Open**. ENVI adds the filename and bands to the Available Bands List.
5. When you open a file for the first time during a session, ENVI automatically places the filename, with all of its associated bands listed beneath it, into the Available Bands List. If a file contains map information as well, a map icon also appears under the filename.

   ENVI also adds output files to the Available Bands List that are the results of processing your data using ENVI’s tools.

Figure D-2: Available Bands List

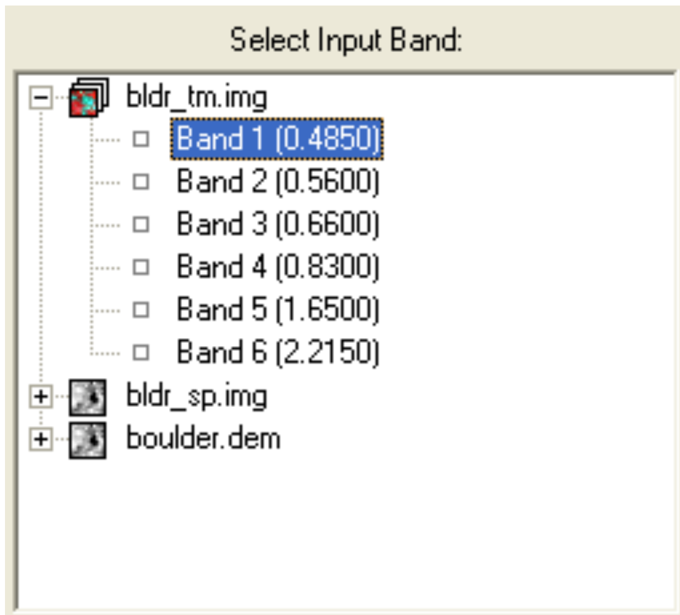


If you open multiple files, all of the files with all of their bands appear in the Available Bands List sequentially, with the most recently opened file at the top of the list. You can fold the bands displayed under each filename to shorten the list length

6. By default, data sets typically display in ENVI in an unfolded state, where a file and all of its bands are immediately visible in the list. In the Available Bands List and other band selection dialogs, many bands may be listed, particularly when

using hyperspectral data. You can fold or hide all of the bands of a data set so that they appear on only one line. This keeps the lists shorter and easier to work with.

Figure D-3: Folded and Unfolded Data Sets



To fold a data set, either:

- Click on the minus symbol (–) next to the filename.
- Double-click on the filename of the data set.
- To fold all data sets in the Available Bands List, right-click in the **Select Input Band** field and select **Fold All Files**, or from the Available Bands List menu bar, select **Options** → **Fold All Files**.

All of the bands of the data set compress and the data set appears with the plus symbol (+) next to the filename, as illustrated in the example in Figure D-3.

To unfold a data set, either:

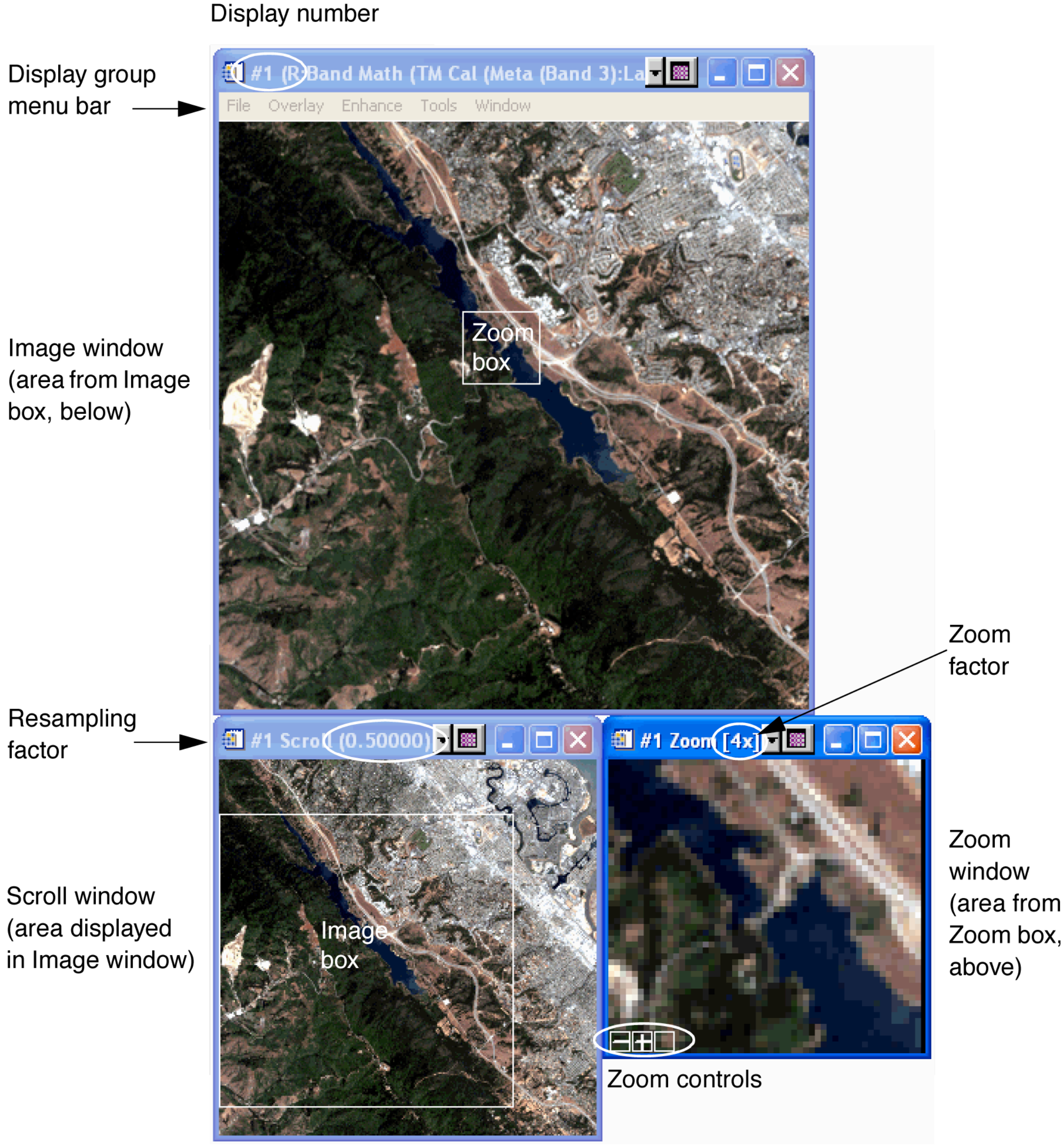
- Click on the plus symbol (+) next to the filename.
- Double-click on the filename.
- To unfold all data sets in the Available Bands List, right-click in the **Select Input Band** field and select **Unfold All Files**.

All of the bands of the data set expand and the data set appears with the minus symbol (–) next to the filename, as illustrated in the example in Figure D-3.
If a band is currently displayed as either a gray scale or RGB image, an asterisk

(*) appears next to the filename when it is folded.

7. To display an image, highlight the band you wish to display and select the “Gray Scale” radio button. The band name appears under the **Selected Band** area.
8. Click **Load Band**. ENVI loads the band into the display group.
9. When you select a file to display from the Available Bands List , a group of windows will appear on your screen allowing you to manipulate and analyze your image. This group of windows is collectively referred to as the *display group* (see Figure D-4). The default display group consists of the following:
   - Image window — Displays the image at full resolution. If the image is large, the Image window displays the subsection of the image defined by the Scroll window Image box.
   - Zoom window — Displays the subsection of the image defined by the Image window Zoom box. The resolution is at a user-defined zoom factor based on pixel replication or interpolation.
   - Scroll window — Displays the full image at subsampled resolution. This window appears only when an image is larger than what ENVI can display in the Image window at full resolution.

Figure D-4: Display Group



ENVI displays all images with a default 2% linear stretch. You can have multiple display groups open at a time, with any combination of gray scale and color images on display.

It is simple to access the location and geometry information in the *.LOC and *.OBS files and relate it to the spectra of the *.RDN files using ENVI. Open and display an image from an *.RDN file as in Step 1) listed above. Then open and display bands from the *.LOC and *.OBS files, or both, in separate windows.

Link the various windows using the **Tools → Link → Link Displays** pull-down menus. Once linked, you can interrogate spectra and simultaneously be provided the longitude, latitude and radius from the *.LOC file as well as values from all ten bands of observation geometry data in the *.OBS files.

For more detailed documentation and user's guides of ENVI and IDL software, visit the ITT Visual Solutions website, http://www.ittvis.com/

Appendix E - M3 Science Data Flow